PB83-105536

Treatment Compatibility of Municipal Waste and Biologically Hazardous Industrial Compounds. Volume I

Oklahoma State Univ., Stillwater

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Jun 82

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-82-075a
June 1982

PB83-105536

TREATMENT COMPATIBILITY OF MUNICIPAL WASTE AND BIOLOGICALLY HAZARDOUS INDUSTRIAL COMPOUNDS

Volume I

by

A.F. Gaudy, Jr., D.F. Kincannon, T.S. Manickam

with

T.R. Blachly, K. Chatterjee, J.A. Chelus
Y.K. Chen, D.E. McCartney, S.Y. Rao
M.P. Reddy and G.D. Whang

Bioenvironmental Engineering Laboratories
School of Civil Engineering
Oklahoma State University
Stillwater, Oklahoma 74074

Grant No. R805242

Project Officer

T.E. Short
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

EPA-287 (Cin.)
(4-76)

BEGIN
FIRST

TYPING GUIDE SHEET

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-82-075a

2.
ORD Report

3. RECIPIENT'S ACCESSION NO.
PB83 105536

4. TITLE AND SUBTITLE
Treatment Compatibility of Municipal Waste and Biologically Hazardous Compounds, Volume I

5. REPORT DATE
June 1982

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
A. F. Gaudy, Jr., D. F. Kincannon, and T. S. Manickham

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Oklahoma State University
School of Civil Engineering
Stillwater, OK 74074

10. PROGRAM ELEMENT NO.
CBGB1C

11. XXXXXXXX/GRANT NO.
R805242

12. SPONSORING AGENCY NAME AND ADDRESS
Robert S. Kerr Environmental Research Laboratory
P. O. Box 1198
Ada, Oklahoma 74820

13. TYPE OF REPORT AND PERIOD COVERED
Final--7/15/77 to 7/15/79

14. SPONSORING AGENCY CODE
600/15

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The overall objective of this research was to gain information on the effect of priority pollutants on the performance of publicly owned treatment works employing activated sludge as the method of secondary treatment. The study was designed to gain information on the effects of a wide array of compounds and to determine the most useful study procedures to be used in assessing effects for the purpose of aiding the Agency in formulating regulatory policy in regard to pretreatment prior to discharge to the publicly owned treatment works.

Batch and continuous-flow bench-scale activated sludge pilot plants were fed settled municipal sewage. The general approach was to compare the performance of control systems with that of comparable systems dosed with various concentrations of priority pollutants. Twenty-four compounds were studied in batch pilot plants; eight of these were also studied in continuous-flow pilot plants operated at a net specific growth rate (μ_n) of 0.2^{-1} (θ_c = 5 days), and four of the eight were also studied in extended aeration pilot plants. Each compound was studied for a period of six months under each mode of operation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Activated Sludge Process Industrial Waste Treatment Pilot Plants Waste Treatment Sludge Environmental Engineering	Bench-scale Plants Priority Pollutants Municipal Wastes Combined Industrial Municipal Treatment	68D

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
203

22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

Mention of trade names or commercial products does not consititute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's air, land, and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report is a study to evaluate the degree of "susceptibility" of refractory and priority pollutants to municipal waste treatment processes and the impact of this susceptibility on industrial pretreatment technology. The study was designed to gain information on the effects of a wide array of compounds and to determine the most useful study procedure to be used in assessing effects. Both batch and continuous flow bench-scale activated sludge pilot plants were utilized in this effort. The results illustrate that batch pilot-plant operation, although more easily facilitated, cannot be used in place of continuous flow pilot studies as a means of gaining information on which to base pretreatment policy regulations.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental Research Laboratory

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

PREFACE

Economic considerations, as well as the applicability of the process to a wide variety of waste components, have fostered the adoption of biological treatment as the major secondary treatment process for many municipal and industrial wastewaters. Activated sludge is one of the most widely used of the biological wastewater treatment processes. In many cases industries discharge pre-treated or untreated wastes to publicly owned treatment plants where their wastes are subjected to treatment along with the household and commercial discharges comprising the municipal sewage. Some of these industrial chemicals may interfere with the treatment process, thus placing the public's investment in the treatment facility in jeopardy. Alternatively, these compounds may pass unchanged through the plant and find their way to the water resource, where their toxic potential militates against the usefulness of the resource.

Formulation of regulatory policy in regard to discharge of specific potentially hazardous (toxic) chemicals to municipal sewage systems requires a sound base of scientific information in regard to their effect on, and fate at, the municipal treatment plant. The breadth and depth of the required investigational effort is of extremely great magnitude and there are no immediately apparent quick ways to assess effects of specific compounds. The overall goal of the study herein and reported was to contribute to the sound data base needed to formulate regulatory policy with regard to high priority (toxic) pollutants and to compare different methods for obtaining such data. The 24 compounds selected for study in this investigation are among the 129 elements or compounds listed as priority pollutants in the consent decree in NRDC vs. Train 8 ERC 2120.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ABSTRACT

The overall objective of this research was to gain information on the effect of priority pollutants on the performance of publicly owned treatment works employing activated sludge as the method of secondary treatment. The study was designed to gain information on the effects of a wide array of compounds and to determine the most useful study procedures to be used in assessing effects for the purpose of aiding the agency in formulating regulatory policy in regard to pre-treatment prior to discharge to the publicly owned treatment works.

Batch and continuous flow bench-scale activated sludge pilot plants were fed settled municipal sewage. The general approach was to compare the performance of control systems with that of comparable systems dosed with various concentrations of priority pollutants. Twenty-four compounds were studied in batch pilot plants; eight of these were also studied in continuous flow pilot plants operated at a net specific growth rate, (μ_n) of 0.2^{-1} $(\Theta_c = 5$ days), and four of the eight were also studied in extended aeration pilot plants. Each compound was studied for a period of six months under each mode of operation.

In batch, only pentachlorophenol and 2-chlorophenol caused increases in soluble residual chemical oxygen demand at feed concentrations of 5 mg/l. None of the eight compounds tested in continuous flow at $\Theta_c = 5$ days showed increased effluent soluble COD at the 5 mg/l dosage, but suspended solids concentrations increased in the effluent of the units dosed with phenol and methylene chloride. Higher dosage levels of several compounds led to leakage of soluble COD and higher suspended solids concentrations in the effluent. Effluents from the extended aeration process were better than from comparable systems at the faster growth rate. From the relatively few analyses made for specific compounds, there was no evidence for excessive pass-through of priority pollutants on publicly owned treatment works.

This report was submitted in fulfillment of Grant No. R805242 by the School of Civil Engineering, Oklahoma State University, under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period July 15, 1977, to July 15, 1979, and the work was completed as of July 15, 1979.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

CONTENTS

Foreword iii

Preface iv

Abstract v

List of Figures. x

List of Tables xvi

Acknowledgments xviii

1. Introduction 1

2. Conclusions 4

3. Recommendations 7

4. Materials and Methods 9

    General experimental plan 9

    Description of pilot plants 11

    Pilot plant feed stock 11

    Analytical techniques. 14

    Routine operational procedures 16

    Auxiliary studies. 18

5. Results and Discussion. 20

    Phase I - Batch pilot plant studies. 20

        Naphthalene 20

        Toluene 24

        Hexachlorobenzene 24

        Benzene 32

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

Preceding page blank

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

  - Phenol. 32
  - Pentachlorophenol 40
  - Nitrobenzene. 40
  - 2-Chlorophenol. 45
  - Anthracene. 45
  - o-Nitrophenol (2-Nitrophenol) 52
  - Hexachloroethane. 58
  - Fluorene. 63
  - Methylene Chloride. 63
  - Carbon Tetrachloride. 63
  - Chloroform. 72
  - Trichloroethylene 72
  - Chlorobenzene 81
  - Tetrachloroethylene 81
  - 4-Chloro, 3-methylphenol. 90
  - Ethylbenzene. 90
  - 1,2-Dichloroethane. 90
  - 1,1,2-Trichloroethane 102
  - Bromoform 102
  - Tetrachloroethane 102

- Phase II - Continuous flow pilot plant studies 114
  - Control Unit. 114
  - Benzene 114
  - Phenol. 119
  - Phenol, Extended Aeration 125

EPA-287 (Cin.)
(4-76)

  - Control Unit. 130
  - Nitrobenzene. 134
  - 2-Chlorophenol. 137
  - 2-Chlorophenol, Extended Aeration 142
  - Control Unit. 142
  - Trichloroethylene 147
  - Methylene Chloride. 152
  - Methylene Chloride, Extended Aeration 157
  - Control Unit 160
  - 1,2-Dichloroethane. 160
  - 4-Chloro, 3-Methyl Phenol 166
  - 4-Chloro, 3-Methyl Phenol, Extended Aeration. . . . 166
- Summary of data. 172
- Fate of Test Compounds 172

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-267 (Cin.)
(4-76)

FIGURES

Number Page

1 Schematic diagram of batch activated sludge reactors 12

2 Schematic diagram of continuous flow activated sludge reactor. . 13

3 Operational results of batch control and naphthalene units . . . 21

4 Stripping of naphthalene in the batch growth reactor 23

5 Growth and COD removal of batch naphthalene unit, dosage=50 mg/l 25

6 Operational results of batch control and toluene units 26

7 Stripping of toluene in the batch growth reactor 27

8 Growth and COD removal of batch toluene unit, dosage=20 mg/l . . 28

9 Operational results of batch control and hexachlorobenzene units 29

10 Growth and COD removal of hexachlorobenzene unit, dosage=50 mg/l 31

11 Operational results of batch control and benzene units 33

12 Stripping of benzene in the batch growth reactor 34

13 Growth and COD removal of batch benzene unit, dosage=20 mg/l . . 35

14 Operational results of batch control and phenol units. 36

15 Stripping of phenol in the batch gowth reactor 38

16 Growth and COD removal of batch phenol unit, dosage=50 mg/l. . . 39

17 Operational results of batch control and pentachlorophenol units 41

18 Stripping of pentachlorophenol in batch growth reactor 42

19 Growth and COD removal of pentachlorophenol unit, dosage=20 mg/l 43

20 Operational results of batch control and nitrobenzene units. . . 44

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Number Page

21 Stripping of nitrobenzene in batch growth reactor 47
22 Growth and COD removal of batch nitrobenzene unit, dosage=50 mg/l 48
23 Operational results of batch control and 2-chlorophenol units . . 49
24 Stripping of 2-chlorophenol in the batch growth reactor 50
25 Growth and COD removal of 2-chlorophenol unit, dosage=50 mg/l . . 51
26 Operational results of batch control and anthracene units 53
27 Stripping of anthracene in the batch growth reactor 55
28 Growth and COD removal of batch anthracene unit, dosage=5 mg/l. . 56
29 Operational results of batch control and 2-nitrophenol 57
30 Stripping of 2-nitrophenol in the batch growth reactor. 59
31 Growth and COD removal of batch 2-nitrophenol unit, dosage=5 mg/l 60
32 Operational results of batch control and hexachloroethane units . 61
33 Growth and COD removal of hexachloroethane unit, dosage=50 mg/l . 64
34 Operational results of batch control and fluorene units 65
35 Stripping of fluorene in the batch growth reactor 66
36 Growth and COD removal of batch fluorene unit, dosage=50 mg/l . . 67
37 Operational results of batch control and methylene chloride units 68
38 Stripping of methylene chloride in the batch growth reactor . . . 70
39 Growth and COD removal of methylene chloride unit, dosage=5 mg/l. 71
40 Operational results of batch control and carbon tetrachloride units 73
41 Stripping of carbon tetrachloride in the batch growth reactor . . 74
42 Growth and COD removal of carbon tetrachloride unit, dosage=5 mg/l 75
43 Operational results of batch control and chloroform units 76
44 Stripping of chloroform in the batch growth reactor 78

Number Page

45 Growth and COD removal of batch chloroform unit, dosage=5 mg/l . 79

46 Operational results of batch control and trichloroethylene units 80

47 Stripping of trichloroethylene in batch growth reactor 82

48 Growth and COD removal of trichlorethylene unit, dosage=5 mg/l . 83

49 Operational results of batch control and chlorobenzene units . . 84

50 Stripping of chlorobenzene in the batch growth reactor 86

51 Growth and COD removal of batch chlorobenzene unit, dosage=5 mg/l 87

52 Operational results of batch control and tetrachloroethylene units 88

53 Stripping of tetrachloroethylene in the batch growth reactor . . 89

54 Growth and COD removal of tetrachloroethylene unit, dosage=25 mg/l 91

55 Operational results of batch control and 4-chloro, 3 methyl phenol units 92

56 Stripping of 4-chloro, 3-methyl phenol in the batch growth reactor 94

57 Growth and COD removal of 4-chloro, 3-methyl phenol unit at 25 mg/l 95

58 Operational results of batch control and ethylbenzene units. . . 96

59 Stripping of ethylbenzene in the batch growth reactor. 98

60 Growth and COD removal of ethylbenzene unit, dosage=25 mg/l. . . 99

61 Operational results of batch control and 1,2-dichloroethane units 100

62 Stripping of 1,2-dichloroethane in batch growth reactor. 103

63 Growth and COD removal of 1,2-dichloroethane unit, dosage=25 mg/l 104

64 Operational results of batch control and 1,1,2-trichloroethane units 105

65 Stripping of 1,1,2-trichloroethane in the batch growth reactor 106

66 Growth and COD removal of 1,1,2-trichloroethane unit, at 25 mg/l 107

67 Operational results of batch control and bromoform units 108

EPA-287 (Cin.)
(4-75)

Number Page

68 Stripping of bromoform in the batch growth reactor 110

69 Growth and COD removal of batch bromoform unit, dosage=25 mg/l . 111

70 Operational results of batch control and tetrachloroethane units 112

71 Stripping of tetrachloroethane in the batch growth reactor . . . 113

72 Growth and COD removal of tetrachloroethane unit, dosage=5 mg/l 115

73 Operational results of continuous flow control (Θ_c=5 days), from July 1977. 116

74 COD removal of control unit. 117

75 Operational results of continuous flow benzene unit (Θ_c=5 days). 118

76 Batch stripping study of benzene in a continuous flow reactor . 121

77 COD removal of continuous flow benzene unit (Θ_c = 5 days) dosage =20 mg/l (top), dosage=50 mg/l (bottom) 122

78 Operational results of continuous flow phenol unit (Θ_c=5 days) . 123

79 Batch stripping study of phenol in a continuous flow reactor . . 126

80 COD removal of continuous flow phenol unit (Θ_c=5 days) dosage =20 mg/l. 127

81 COD removal of continuous flow phenol unit (Θ_c=5 days) dosage = 50 mg/l 128

82 Operational results of continuous flow phenol unit (extended aeration) 129

83 COD removal of continuous flow phenol unit (extended aeration) dosage=50 mg/l. 131

84 Operational results of continuous flow control (Θ_c=5 days), from January 1978 133

85 Operational results of continuous flow nitrobenzene unit (Θ_c=5 days) 135

86 COD removal of continuous flow nitrobenzene unit (Θ_c=5 days) dosage=5 mg/l 138

87 Operational results of continuous flow 2-chlorophenol unit (Θ_c=5 days) 139

Number Page

88 Batch stripping study of 2-chlorophenol in a continuous flow reactor 141

89 COD removal of continuous flow 2-chlorophenol unit (Θ_c=5 days), dosage=20 mg/1. 143

90 Operational results of continuous flow 2-chlorophenol unit (extended aeration) 144

91 COD removal of continuous flow 2-chlorophenol unit (extended aeration), dosage=5 mg/1. 146

92 Operational results of continuous flow control (Θ_c=5 days), from July 1978. 148

93 Operational results of continuous flow trichloroethylene unit (Θ_c=5 days) 149

94 COD removal of continuous flow trichloroethylene unit (Θ_c=5 days), dosage=5 mg/1. 151

95 Operational results of continuous flow methylene chloride unit (Θ_c=5 days) 153

96 Batch stripping study of methylene chloride in a continuous flow reactor. 155

97 COD removal of continuous flow methylene chloride unit (Θ_c=5 days), dosage=25 mg/1 156

98 Operational results of continuous flow methylene chloride unit (extended aeration) 158

99 COD removal of continuous flow methylene chloride unit (extended aeration), dosage=25 mg/1 161

100 Operational results of continuous flow control (Θ_c=5 days), from January 1979 162

101 Operational results of continuous flow 1,2-dichloroethane unit (Θ_c=5 days) 163

102 COD removal of continuous flow 1,2-dichloroethane unit (Θ_c=5 days), dosage=5 mg/1. 165

103 Operational results of continuous flow 4-chloro, 3-methyl phenol unit (Θ_c=5 days). 167

EPA-287 (Cin.)
(4-76)

Number Page

104 COD removal of continuous flow 4-chloro, 3-methyl phenol unit (θ_c=5 days), dosage=25 mg/l 169

105 Operational results of continuous flow 4-chloro, 3-methyl phenol unit (extended aeration). 170

106 COD removal of continuous flow 4-chloro, 3-methyl phenol unit (extended aeration) dosage=25 mg/l. 173

TABLES

Number Page

1 Compounds Studied and Operational Conditions 10

2 Columns and Temperatures for Gas Chromatographic Analysis of Selected Compounds Using Concentration Procedure 1 15

3 Columns and Temperatures for Gas Chromatographic Analysis of Selected Compounds Using Concentration Procedure 2 17

4 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Naphthalene and Toluene. 22

5 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Hexachlorobenzene and Benzene. 30

6 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Phenol and Pentachlorophenol 37

7 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Nitrobenzene and 2-Chlorophenol. 46

8 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Anthracene and 2-Nitrophenol 54

9 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Hexachloroethane and Fluorene. 62

10 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Methylene Chloride and Carbon Tetrachloride 69

11 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Chloroform and Trichloroethylene 77

12 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Chlorobenzene and Tetrachloroethylene . . 85

13 Statistical Analysis of Operational Data for Batch Activated Sludge Dosed with 4-Chloro, 3-Methyl Phenol 93

14 Statistical Analysis of Operational Data for Batch Activated Sludge Dosed with Ethylbenzene. 97

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Number Page

15 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with 1,2 Dichloroethane and 1,1,2 Trichloroethane 101

16 Statistical Comparison of Operational Data for Batch Activated Sludges Dosed with Bromoform and Tetrachloroethane 109

17 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with Benzene. 120

18 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with Phenol 124

19 Statistical Analysis of Operational Data for an Extended Aeration Process Dosed with Phenol 132

20 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with Nitrobenzene . . . 136

21 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with 2-Chlorophenol . . 140

22 Statistical Analysis of Data for an Extended Aeration Process Dosed with 2-Chlorophenol. 145

23 Statistical Comparison of Operational Data for an Undosed Control and One Dosed with Trichloroethylene 150

24 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with Methylene Chloride 154

25 Statistical Analysis of Data for an Extended Aeration Process Dosed with Methylene Chloride. 159

26 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with 1,2,-Dichloroethane 164

27 Statistical Comparison of Operational Data for an Undosed Control Activated Sludge Process and One Dosed with 4-Chloro, 3-Methyl Phenol 168

28 Analysis of Data for Extended Aeration Process Dosed with 4-Chloro, 3-Methyl Phenol. 171

29 Summary of Effects of Priority Pollutants 174

30 Specific Compound Analysis. 179

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ACKNOWLEDGEMENTS

The conduct of this research required a coordinated effort on the part of many people.

We are grateful for the cooperation extended to us by the transportation group of the School of Civil Engineering. Without daily use of their van the obtaining of sufficient sewage for the conduct of the project would have been extremely difficult.

Once the experimental schedule for such a piece of contractual research is established, fulfillment of the agreement demands that the work progress on a definite time table. The maintenance of equipment and services for such a project is vital and the researchers wish to acknowledge the loyal efforts of Mr. Cecil Sharp in this regard.

Some of the graduate student investigators who worked on this project did so, not in conjunction with thesis research as is the usual mode for university project work, but as a professional undertaking over and above an already strenuous thesis research program. Messrs. T.R. Blachly, K. Chatterjee, Y.K. Chen and M.P. Reddy deserve special mention in this regard. The project could not have been conducted within the experimental time table without their willingness to serve "double duty".

We are also indebted to Dr. Elizabeth T. Gaudy, Professor of Microbiology, Oklahoma State University, for her review and helpful suggestions during the writing and compiling of this report.

EPA-287 (Cin.)
(4-76)

SECTION 1

INTRODUCTION

The magnitude of the informational base required for formulation of regulatory policy to protect the public health and the public investment in biological treatment facilities is best realized by considering the engineered natural process employed for treatment. It is biological, and the kinds of microorganisms which comprise the biomass (the activated sludge) are subject to change because of environmental pressures. Indeed, the species making up the sludge may change because of interspecies interactions regardless of environmental conditions in which the bio-process functions. Thus, it is no easy chore to determine whether a particular chemical at low concentrations is responsible for an observed malfunction of an activated sludge process. Also, in setting a pre-treatment standard, it should be considered that the kinds and concentrations of priority pollutants which cannot be tolerated are related to the general "health" of the treatment plant at the time of receiving the priority pollutant or combinations of toxic components.

There is considerable difference of opinion as to the most "healthy" way to operate various activated sludge facilities. Although there has been some interest in these matters for many years in various sectors of the scientific community, there has been little manifestation of societal interest in the way of support of such investigations. Support awaited the practical need to establish regulations to protect public health and investment against compounds generally accepted or suspected to be toxic. Paradoxically, the need for regulation is at present so urgent that much of the desirable depth of investigation needed as a base for establishing relatively unassailable and just regulatory policy may be sacrificed in favor of speedy action in formulating the policies which are required in order to comply with the law. The latter alternative is defensible as overall sound environmental policy but it could lead to unneeded and/or overly conservative regulations which could do more economic harm than environmental good.

The above considerations are among those which entered into decisions as to the design of this two-year research project. The aim was to study as many compounds as possible, but for sufficient time and with sufficient depth of investigation to provide reliable and useful information. The most critical need is for assessment of types and magnitudes of effects rather than determination of mechanistic causation for any particular detrimental effect. Thus, it is desirable to screen as quickly as possible a wide array of compounds so that those which are easily accommodated at the publicly owned treatment works or do not cause deleterious effects can be eliminated from further in-depth or remedial study.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

The major problems caused by toxic compounds in publicly owned treatment works would be those affecting the concentrations of soluble organic matter and suspended solids in the effluent, since the justification for constructing secondary treatment plants is the removal of soluble and particulate organic matter. The most important effect is on the biochemical efficiency of the process as measured by the amount of soluble organic matter remaining in the treated wastewater, e.g., residual chemical oxygen demand (COD) or total organic carbon (TOC). Of somewhat lesser importance is the effect a toxicant may have on the concentration of suspended solids after settling. This is a less important consideration because there are engineering remedies which can alleviate periodically high effluent suspended solids concentrations, e.g., addition of flocculating chemicals or installation of sand filters, etc. However, there is little that can be done in the way of engineering remedies to counteract loss in substrate removal ability due to the presence of a toxicant in the feed.

The effect of the treatment plant on a toxic component is also an important consideration and the fate of the compound may be biological degradation, removal and accumulation in the sludge or pass-through in the effluent. It should also be mentioned that reliable analyses for small quantities of some of the priority pollutants are not yet available and that the cost of performing analyses which are available is high. Thus, routine analyses for priority pollutants during the investigation was beyond the budgetary scope of the project. However, it would have been unfortunate if the massive amount of experimentation herein reported had been conducted without providing for occasional analyses of samples of feed, mixed liquor suspended solids and effluent for specific compounds being dosed to the treatment processes being studied.

Many more batch than continuous flow activated sludge processes can be operated for a given sum and it was important to determine whether batch data could be reliable in determining metabolic response to toxic components. Thus, one phase of the investigation involved the operation of bench-scale batch activated sludge systems. The usefulness of batch data can be assessed best by comparing results with those from continuous flow activated sludge pilot plants operated concurrently on the same feed material. The main basis for comparison was performance with respect to removal of soluble COD. Since the selectable operational conditions for a continuous flow activated sludge pilot plant may affect response to toxicants, it was desirable to vary operational conditions in the study. One broadly accepted operational control for various types of activated sludge processes is the net specific growth rate (μ_n). This parameter is measured as the net specific rate of excess sludge production; thus, it is the reciprocal of the mean sludge retention time or sludge age (θ_c). There was some cause to believe that systems operated at a slow growth rate (greater sludge retention time) would give different results than higher rate activated sludge systems. Accordingly, some compounds were studied concurrently in an extended aeration process, fast growth rate activated sludge systems and batch pilot plants.

Since effects of various concentrations of toxicants may not be rapidly manifested, it was not feasible, for the sake of rapid accumulation of data, to shorten the period of study for any specific compound. In designing the current studies, six months was allowed for investigation of each compound. The main line of study was the accumulation and analyses of performance data for the various pilot plants in response to varying dosages and modes of dosage of specific priority pollutants. Auxiliary short-term batch studies were made to assess the rate of purification under various dosages of toxic compounds and to determine the degree of strippability of the priority pollutants under conditions of aeration extant in the pilot plants.

In addition to gaining information on biological effects of specific compounds on activated sludge, this study was designed to help provide information needed to formulate pre-treatment policy. The reasoning for such an objective is that it is not yet known which is the most critical mode of study or which are the most critical data to gather. Also, it is emphasized that the responsibility for obtaining such information is not entirely that of the regulatory agency. Such responsibility is certainly shared by those who produce and discharge the pollutants. It is essential, however, that the modes and techniques of study of regulator and producer be compatible and it is to the design of requisite studies on any particular toxicant.

The conclusions and recommendations which follow, in the main, fulfill the above objectives. The basis for further recommendations and conclusions are presented in the body of the report which consists of the "Materials and Methods" and "Results and Discussion" sections. A detailed appendix containing tabulation of all results obtained during the research project is available from EPA but, because of its size, it is not made an appendix to this report. Instead it is published as Volume II of this report.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/2"
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-76)

SECTION 2

CONCLUSIONS

1. Based on the results of pilot plant studies and upon observations during the two-year experimental period, as well as results of auxiliary studies made as the work progressed, the following conclusions with respect to the 24 priority pollutants examined seem warranted.

   a. Of the 24 compounds studied in batch systems, only two (pentachlorophenol and 2-chlorophenol) gave evidence of causing metabolic stress to the system, as judged by comparison of residual soluble COD in the test unit and control unit for steady dosage at a feed concentration of 5 milligrams per liter (mg/l). At higher concentrations (20-25 and 50 mg/l), there was evidence for metabolic disturbance for only one additional compound, 4-chloro, 3-methylphenol.

   b. For the eight compounds tested in the continuous-flow activated sludge pilot plants operated at $\mu_n = 0.2$ days $^{-1}$, there was no evidence for increased soluble COD in the effluent at the 5 mg/l dosage. At this lower dosage, there was evidence for increased suspended solids in the effluent of pilot plants dosed with phenol and methylene chloride. At the higher dosage levels, there was evidence for an increase in soluble COD and suspended solids in the effluent for the pilot plant dosed with phenol. For the units dosed with 2-chlorophenol, methylene chloride and dichloroethane, soluble COD in the effluent was not affected but there was an increase in effluent suspended solids concentration. Under alternating concentration levels (daily changes) there was increased soluble COD and suspended solids in the effluent for the unit dosed with trichloroethylene. For the pilot plants dosed with nitrobenzene, 2-chlorophenol, methylene chloride and 1,2-dichloroethane, cyclic loading led to increased suspended solids in the effluent.

   c. For the four compounds tested in the extended aeration pilot plant, there was evidence for increased soluble COD in the effluent only from the unit dosed with phenol at the 5 mg/l dosage level. There was no increase in effluent suspended solids in any of the four systems at this dosage level. At the higher levels of dosage (20-25 and 50 mg/l) there was evidence for increased soluble COD and suspended solids only in the units dosed with phenol. Also, only in the unit dosed with phenol was there evidence for disturbance of effluent quality when dosage was changed on alternate days.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Based on the relatively few analyses made there was no evidence for massive pass-through of any of the compounds for which specific analytical determination was made even at the high dosage level of 50 mg/l. However, small quantities of some of the compounds were detected in the effluents and more detailed analytical procedures are needed to adequately address the question of pass-through of small concentrations of the priority pollutants.

2. From the results of this study there was evidence that the effluents of the extended aeration pilot plants were lower in soluble COD and particularly in suspended solids concentration than effluents from comparable faster growing systems. Among reasons for such results may be the lower mass loading rate, i.e., higher biomass concentration and longer mean hydraulic retention time. The reason for the lower suspended solids concentration is probably due to generally greater abundance of protozoa in this sludge as compared to the more rapidly growing system. Generally in the faster growing systems, an increase in dosage of the test compound appeared to cause more serious reduction in protozoan activity than in the extended aeration system. Thus, while the biomass with fewer grazing species could provide nearly equal efficiency with respect to residual soluble COD, it was not possible with respect to suspended solids concentration in the effluent. Therefore, it must be concluded that in designing study procedures to assess effects of priority pollutants on activated sludges, the ecological considerations as reflected in effluent clarity as well as other aspects of ecology, such as limiting effects on species diversity should be included as parameters for assessment.

3. In regard to study techniques for assessment of effects of priority pollutants on publicly owned treatment works, it is concluded that batch pilot plant operation, although more easily facilitated, cannot be used in place of continuous flow pilot plant studies as a means of gaining information on which to base pretreatment policy regulations. The results herein obtained on the eight comparable systems led to different conclusions for some of the compounds based solely on one or the other set of data. For example, in batch there was increased soluble residual COD at the 5 mg/l dosage level of 2-chlorophenol but there was no effect on the faster growing continuous flow activated sludge system. There was a deleterious effect for 4-chloro, 3-methyl phenol at higher concentrations in batch but there was no comparable effect in the continuous flow unit. On the other hand, phenol showed no deleterious effect in the batch system but did increase soluble residual COD in the continuous flow system. It cannot be said that the batch data gave either a less or more sensitive estimate of effects based on these results. Thus, they cannot be relied upon as a replacement for continuous flow pilot plant studies.

The general approach and the allotted time for study per compound in continuous flow pilot plants employed in these studies do seem ample for establishing a base for determining requirements for pretreatment and pretreatment policy in regard to a particular priority compound.

EPA-287 (Cin.)
(4-76)

However, there are ways in which the study of such priority pollutants can be improved and these are listed in the recommendation section which follows.

EPA-287 (Cin.)
(4-76)

SECTION 3

RECOMMENDATIONS

It is recommended that the general approach to study of the effects of priority pollutants which was followed in this work be extended to include other priority pollutants. However, some changes in emphasis and study techniques are needed. These are described below, along with the justifications for them. The primary objective of the recommended studies is the same as that of the study reported herein, i.e., the amassing of scientific information upon which EPA can base regulatory policy in regard to pre-treatment requirements for admission of industrial wastes containing priority pollutants to publicly owned treatment works employing the activated sludge process.

1. A study period of six months for each priority pollutant in continuous flow bench-scale pilot plants is needed because of the variable nature of the heterogeneous biomass. Although they may provide useful information, batch pilot plant studies should be abandoned as a basis for formulation of regulatory policy because, as observed in the current investigation, operational environment, e.g., different sludge growth rates in continuous flow reactors, effected changes in the ecology of the sludge, which translated to changes in effluent quality in the presence of various toxicants. The much greater difference in operational environment between batch and continuous flow systems makes batch results essentially non-transferable to the continuous flow situations for which regulatory policy must be developed.

2. Bench-scale, continuous-flow pilot plants should be run, on municipal waste relatively devoid of industrial wastes, at three or more net specific growth rates, e.g., high rate, standard rate and extended aeration. As a means of economy, one control run at nominally standard rate could be used.

3. Variations in dosage and mode of its administration should include:

    a. Steady dosage with relatively low concentrations of toxicant, e.g., 5 to 20 mg/l.

    b. Variations in mode of dosage, including steady concentration levels and pulsating levels, with various time periods of resting between dosings.

    c. Steady and pulsating dosages with combinations of priority pollutants. The combinations can be selected in accordance with the

EPA-287 (Cin.)
(4-76)

chemical composition of wastes from various manufacturing processes.

4. Analyses run to assess the comparative performance of control and dosed systems should include the following:

   a. The analyses employed in the current study. However, a somewhat greater amount should be budgeted for analyses for specific toxicants.

   b. Analyses for various forms of nitrogen to assess effects on nitrification in the extended aeration process.

   c. More detailed observations on changes in predominant types of microorganisms. This is warranted because the presence of toxicants in the system can precipitate changes in the biokinetic and physical properties of the sludge which decrease effluent quality. At the least, detailed logs of observations of wet mount samples for relative changes in bacterial forms, fungi, protozoa, crustacea, etc., coupled with use of simple staining techniques, e.g., India ink stains for slime capsules, etc., could provide semi-quantitative information which would be helpful in making regulatory decisions.

   d. Auxiliary batch growth studies to establish whether the presence of the toxicant causes changes in the biokinetic constants used in design and operational models.

5. Since the need to obtain the required data base is so urgent, it is recommended that EPA evaluate the results, conclusions and recommendations of the present project, along with those of others it has sponsored, and begin the process of formalizing the study techniques, experimental protocol and analysis of data to be used in further studies. Following this, an extensive investigational program, using the finalized protocol, accomplished partly within the agency and partly through research contracts, could supply the information needed to establish safe and equitable regulatory policy.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 4

MATERIALS AND METHODS

GENERAL EXPERIMENTAL PLAN

The research project was conducted in two major phases which proceeded concurrently. Twenty-four compounds on the priority compound listing were studied in batch pilot plants (Phase I). Eight of these were also studied in continuous-flow pilot plants and four of these were studied in extended aeration systems as well(Pase II).

The experimental period covered two years and each compound was studied for a period of approximately six months. The work was thus divided into four periods of six-months duration in each of which six compounds were studied in batch and two in continuous-flow pilot plants. Undosed control systems were also run in batch and continuous flow operations.

The organizational scheme was such that one investigator could run three batch pilot plants: an undosed control and two test units. The study of six compounds concurrently required the services of three investigators and provided for three control systems.

In addition, four continuous-flow activated sludge pilot plants were run concurrently: one undosed control at $\mu_n = 0.2$ days^{-1}, two test compound units at $\mu_n = 0.2$ days $^{-1}$ and one test compound extended aeration unit. Each pilot plant required the services of one investigator. A listing of the compounds studied and the operational conditions under which they were studied is given in chronological order in Table 1.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 1. COMPOUNDS STUDIED AND OPERATIONAL CONDITIONS

	Continuous Flow		
Batch	$\mu_n = 0.2$ days^{-1}	Extended aeration	Period
Naphthalene	-	-	7/15/77
Toluene	-	-	
Hexachlorobenzene	-	-	to
Benzene	Benzene	-	
Phenol	Phenol	Phenol	1/15/78
Pentachlorophenol	-	-	
Nitrobenzene	Nitrobenzene	-	1/15/78
2-Chlorophenol	2-Chlorophenol	2-Chlorophenol	
Anthracene	-	-	to
2-Nitrophenol	-	-	
Hexachloroethane	-	-	7/15/78
Fluorene	-	-	
Methylene Chloride	Methylene Chloride	Methylene Chloride	7/15/78
Carbon Tetrachloride	-	-	
Chloroform	-	-	to
Trichloroethylene	Trichloroethylene	-	
Chlorobenzene	-	-	1/15/79
Tetrachloroethylene	-	-	
4-Chloro,3-methyl phenol	4-Chloro,3-methyl phenol	4-Chloro,3-methyl phenol	1/15/79
Ethylbenzene	-	-	to
1,2-Dichloroethane	1,2-Dichloroethane	-	
1,1,2-Trichloroethane	-	-	6/15/79
Bromoform	-	-	
Tetrachloroethane	-	-	

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

EPA-287 (Cin.)
(4-76)

DESCRIPTION OF PILOT PLANTS

Batch Pilot Plants

A diagram of a batch reactor setup is shown in Figure 1. The reactors were fashioned from 3.75-inch diameter Pyrex glass tubing. The total volume of each reactor was 3.5 liters and a reaction volume of 3.0 liters was employed in the studies. Diffused air was supplied at an airflow rate of 2000 cubic centimeters (cc) per minute through a single carborundum diffuser.

Continuous Flow Pilot Plants

A diagram of the continuous flow reactors is shown in Figure 2. Volumes of aeration chambers and settling compartments for the pilot plants operated at $\mu_n = 0.2$ hours^{-1} were approximately equal. The size of the pilot plants varied somewhat; the smallest aeration chamber volume was 2.7 liters and the largest was 3.6 liters. The aeration and settling compartments are separated by an adjustable baffle wall. The mean hydraulic retention time in the aeration chamber was 8 hours for systems employing a nominal μ_n of 0.2 days^{-1} ($\Theta_c = 5$ days). The extended aeration activated sludge pilot plant was of the same type shown in Figure 2 but it was somewhat larger. The aeration chamber was 7.8 liters and the settling chamber was 4.5 liters. The mean hydraulic retention time in the extended aeration plant was 24.7 hours total, 15.7 hours aeration and 9 hours in the settling tank.

PILOT PLANT FEED STOCK

The normal feed stock consisted of effluent from the primary clarifier of the Stillwater Municipal Sewage Treatment Plant. A large supply of sewage was obtained daily for the feeding of the nine batch reactors and four continuous-flow reactors which were run concurrently throughout this investigation. Examination of the characteristics of the sewage of Stillwater early in the investigation revealed an average total COD of 137 mg/l and average soluble COD of 75 mg/l; average total biochemical oxygem demand (BOD_5) was 39 mg/l and soluble BOD_5 averaged 21 mg/l. Thus, in order to maintain adequate feed strength, the municipal sewage was supplemented with 200 mg/l of glucose and 75 mg/l of ammonium sulfate. No buffer or other salts were added. This mix, municipal sewage plus the supplement noted above, comprised the feed throughout the study except on a very few occasions when the COD of the sewage was extremely high and there was a tendency for foaming. On these days the sewage was diluted. In general, the strength of the sewage fed to the pilot plants varied in accordance with the normal variations in the municipal sewage of Stillwater. To this base feedstock, various concentrations of the test compound were added as desired during the conduct of the experimentation. Concentrations used were 4, 20 or 25, and 50 mg/l in the feed. This concentration range was chosen to provide a conservative estimate of the effect of the compounds, since a concentration of 50 mg/l is much higher than would be expected at a municipal treatment plant.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
9-7/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

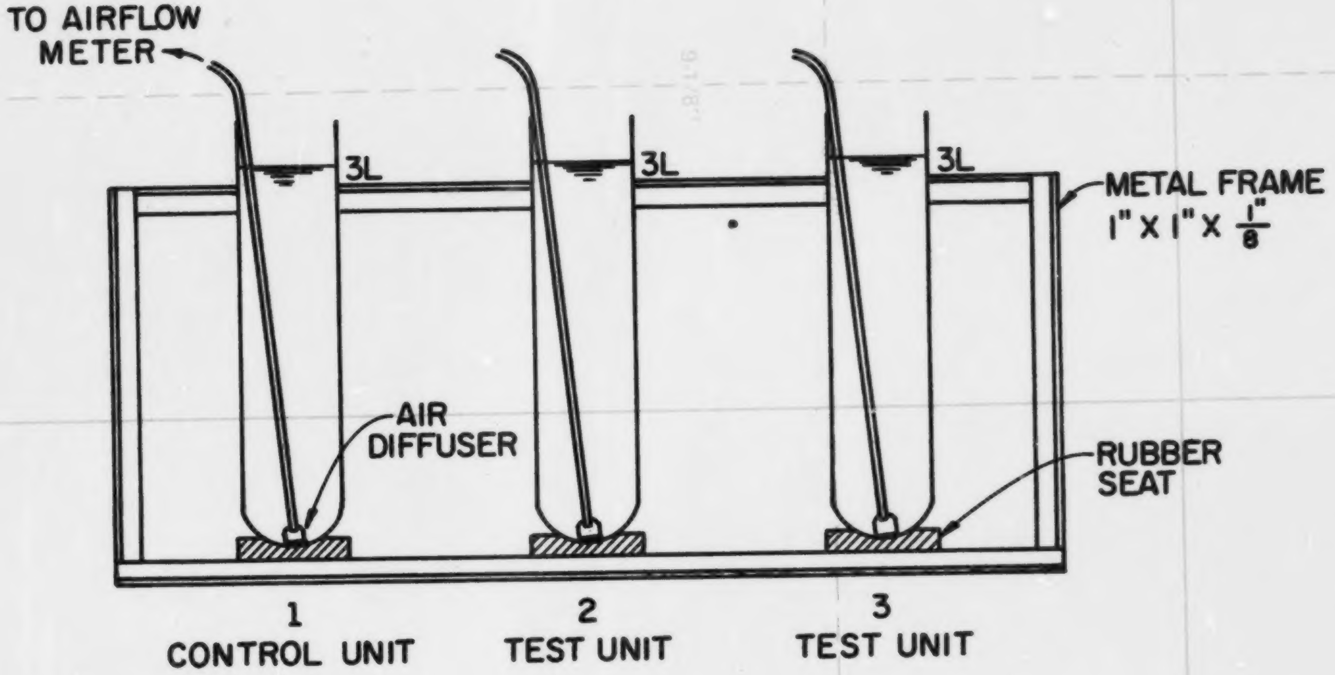
TO AIRFLOW METER
3L
3L
3L
METAL FRAME
1" X 1" X 1/8"
AIR DIFFUSER
RUBBER SEAT
1
CONTROL UNIT
2
TEST UNIT
3
TEST UNIT

Figure 1. Schematic diagram of batch activated sludge reactors.

EPA-287 (Cin.)
(4-76)

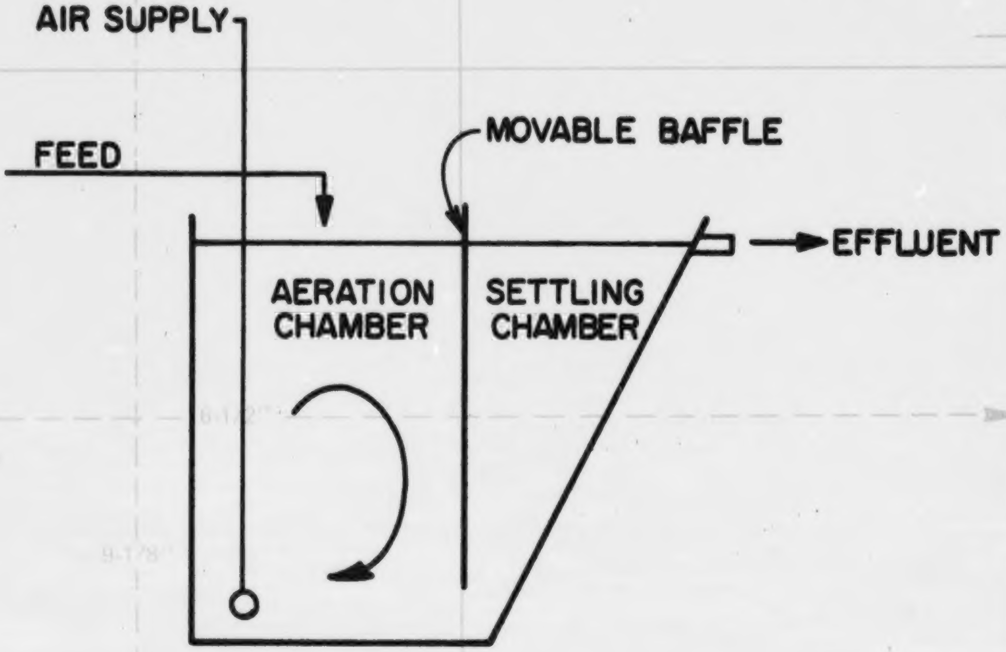
AIR SUPPLY
FEED
MOVABLE BAFFLE
EFFLUENT
AERATION CHAMBER
SETTLING CHAMBER

Figure 2. Schematic diagram of continuous flow activated sludge reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

ANALYTICAL TECHNIQUES

The major analytical techniques employed were COD, as a measure of total and soluble organic matter in the influent and effluent and membrane filter solids [(0.45 micron (μ) pore size] as a measure of mixed liquor suspended solids and suspended solids in the influent and effluent samples. These analyses were run in accordance with "Standard Methods for the Examination of Water and Wastewater".

Some determinations were run daily or on alternate days, while others were run only occasionally. In the latter category, samples were taken for measurement of TOC, using the Beckman Model 915 and for measurement of total oxygen demand (TOD), using the Ionics Corporation Model 1248. TOD samples were frozen for later analysis.

Dissolved oxygen, pH, and temperature were measured periodically in the pilot plant reactors. During each experimental period, several samples were taken for analysis of the test compounds. Analyses were performed using an F and M Research Chromatograph (Model 810) with a flame ionization detector. Helium, the carrier gas, was delivered at a flow rate of 25 milliliters per minute (ml/min). The flame was fueled with air (500 ml/min) and hydrogen fueled at (47 ml/min). The injection port temperature was maintained at 250° C; the detector temperature was 230°C. Samples from the feed, effluent and mixed liquor were analyzed. Generally, a sample was analyzed at least once per each test compound dosing period. In some instances, the biological solids of the mixed liquor samples were separated from the liquid and were resuspended in distilled water for analysis. In most cases samples were frozen until they were analyzed.*

Generally, analytical techniques followed guidelines presented in the EPA Document, "Sampling and analysis procedure for screening of industrial wastes for priority pollutants", March, 1977 (revised April, 1977). An important part of the gas chromatography analytical technique is concentration of the compound in question. Two techniques were employed. The first was extraction with methylene chloride at the appropriate pH for the compound. Feed samples were 100 ml in volume while non-feed samples were 500 ml in volume. Each sample was subjected to three sequential extractions with methylene chloride. Volume ratios of methylene chloride to sample were as follows: 1/8⟶1/20⟶1/20. The combined extracts were reduced by evaporation to a volume of 1 ml. The injection volume was 1.0 microliter. The compounds for which this procedure was employed, as well as the columns and column temperatures used, are listed in Table 2. The second concentration technique used, applicable only to the volatile compounds, was the trap and purge method. This was accomplished using a Tekmar (Model LSC-1) liquid sample concentrator with a Tenax Gas Chromatograph silica gel trap. Operating conditions for this piece of equipment are as follows:

---

* The frozen samples were transported to the Oklahoma State University Department of Chemistry, where they were analyzed by Carl Rapson under the supervision of Professor L. Varga.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 2. COLUMNS AND TEMPERATURES FOR GAS CHROMATOGRAPHIC ANALYSIS OF SELECTED COMPOUNDS USING CONCENTRATION PROCEDURE 1

Compound	Column	Temperature
Phenol	FFAP[1]	145° C
2-chlorophenol	FFAP	135° C
2-nitrophenol	FFAP	135° C
4-chloro,3-methyl phenol	Sp-2250[2]	140° C
Hexachloroethane	Sp-2250	75° C
Naphthalene	Sp-2250	75° C
Nitrobenzene	Sp-2250	85° C
Fluorene	Sp-2250	150° C
Hexachlorobenzene	Sp-2250	160° C
Anthracene	Sp-2250	185° C

---

1. 5% FFAP on 80/100 mesh Chromosorb W-HP 6' x 1/8".

2. 3% Sp-2250 on 100/120 mesh Supelcoport 6' x 1/8".

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Purge gas - Helium 20 (psi)
Purge flow - 40 - 43 ml/min
Purge time - 12 min
Desorb temp. - 180° C
Desorb time - 4 min
Desorb gas - Helium which was connected directly to gas chromatographer
Sample size - 5 ml for feeds
25 ml for non-feeds

The compounds, columns and column temperatures for this group of compounds are listed in Table 3.

ROUTINE OPERATIONAL PROCEDURES

Batch Pilot Plants

The general feeding procedure followed by each operator of each set of three batch reactors (control and two test units) was as follows. Any solids accumulation on the side wall was carefully scraped down and mixed throughly in the reactor. One liter of mixed liquor was withdrawn from each unit. The air diffusers were removed and the remaining two liters were allowed to settle for one hour. After settling, a liter of supernatant was withdrawn from each unit. Glucose and ammonium sulfate were added from concentrated stock solutions and the dosages of priority pollutants were added to the appropriate test reactors. All units were then returned to the 3-liter mark with primary effluent from the Stillwater Municipal Sewage Treatment Plant. On a very few occasions, anti-foam spray was used to prevent foaming.

It is important to note that the dosages of test compounds given apply to the feed. That is, when dosages were either 5, 20, 25 or 50 mg/l of test compound, the concentration of the compound in the reactor at the beginning of each daily 23-hour aeration period would be two-thirds of that which was fed (assuming that the concentration in the one liter of mixed liquor retained from the previous day was 0).

During this study, dosage levels were increased as follows. After a short period of no dosage, the test compound was added to the feed at a concentration of 5 mg/l. After examining the effect of the compound for a period of time, the dosage was increased to 25 mg/l; after a further period of examination, the dosage was increased to 50 mg/l. After a period of operation at the steady dosage level of 50 mg/l, the unit was subjected to daily cycling of the concentration of test compound. Usually the cycling was as follows: 50 ⟶ 25 ⟶ 50, followed by 25 ⟶ 0 ⟶ 25 mg/l. In some studies resting periods of longer than 24 hours at 0 dosage were examined. Samples were taken from the mixed liquor immediately before each wasting and feeding period and immediately after feeding the reactors and bringing them to the 3-liter operating volume. Usually samplings were made to assess performance on alternate days; however, during cyclic shocking of the units with toxic compounds, samples were taken daily.

EPA-287 (Cin.)
(4-76)

TABLE 3. COLUMNS AND TEMPERATURES FOR GAS CHROMATOGRAPHIC ANALYSIS OF SELECTED COMPOUNDS USING CONCENTRATION PROCEDURE 2

Compound	Column	Temperature
Methylene chloride	Carbowax[1]	70° C
Chloroform	Carbowax	100° C
1,2-dichloroethane	Carbowax	120° C
Carbon tetrachloride	Carbowax	125° C
Trichloroethylene	Carbowax	150° C
1,1,2-trichloroethylene	Carbowax	160° C
Bromoform	Carbowax	160° C
Tetrachloroethylene	Carbowax	160° C
1,1,2,2-tetrachloroethane	Carbowax	160° C
Chlorobenzene	Carbowax	160° C
Ethylbenzene	Carbowax	160° C

[1] 0.2% Carbowax 1500 on 60/80 Carbopac C 8' x 1/8" preceded by 3% Carbowax 1500 on 60/80 Chromosorb WAW-DCMS 1' x 1/8".

Continuous Flow Pilot Plants

Activated sludges were developed in batch operation using glucose-supplemented primary effluent from the Stillwater Municipal Sewage Treatment Plant. After building up the sludge concentration, the pilot plants were operated in continuous flow at a mean hydraulic retention time of 8 hours. The "nominal" growth rate was maintained at 0.2 days^{-1} (Θ_c = 5 days) by proportional wasting of mixed liquor after removing the baffle separating the aeration and settling chambers. The general procedure in running at Θ_c = 5 days was to waste 1/6 of the total mixed liquor. This wastage together with the biomass lost as effluent suspended solids was estimated to provide the desired growth rate. The mean hydraulic retention time in the extended aeration pilot plant was 15.7 hours and no sludge other than that used for sampling was wasted at any time during the study. Thus, the growth rate was expected to be very low; it was limited by the suspended solids concentration in the effluent.

The performance of these systems was monitored at 2-day intervals, using essentially the same parameters as were used for the batch pilot plants, with the exception that many more samples to assess effluent suspended solids were run routinely as one of the performance parameters for the continuous flow pilot plants. Sample size for the influent was generally 20 ml whereas effluent sample size varied from 40 to 100 ml. For the relatively few samples taken for determination of specific compounds in either the feed, mixed liquor or effluent, the sample size was 1.0 liter.

AUXILIARY STUDIES

During the period of pilot plant operation on each priority pollutant, it was advisable to gain information on the effect of varying concentrations of priority pollutant on the rate of COD removal and sludge accumulation in separate short-term batch studies using activated sludge samples taken from either the batch or the continuous flow pilot plants. Also, since a number of the priority pollutants are volatile, i.e., they can be stripped under atmospheric conditions by agitation, it was desirable to gain some information on the ease of strippability for each compound.

Studies of Rate of Purification

Batch studies to gain information on the relative rates of purification were usually conducted on the day the concentration of priority pollutant was changed in the pilot plant. These studies were conducted in a number of ways. At times samples of the sludge wasted from the pilot plant were used as initial inocula. Therefore, in this type of study the initial biomass concentration would be low. In other studies the samples for rate of removal were taken directly from the units after they were fed. This latter type of procedure applied mainly to the batch pilot plant studies. For study of continuous flow units, samples of excess sludge were used and the batch studies were initiated with a low biomass concentration. In studying the behavior of the extended aeration sludge a small portion of sludge was taken

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

from the unit to facilitate the batch studies. Usually three reactor conditions were employed in the auxiliary batch studies; an undosed control, a system dosed with the concentration of test compound which was being fed to the pilot plant and a system which received a higher dosage than that which was being fed. Samples were taken frequently during the early hours of the batch study and less frequently until the 23rd or 24th hour.

Stripping Tests

Each of the priority pollutants was tested for its stripping characteristics in a batch system. Stripping tests were conducted in the pilot plant reactors under the identical aeration conditions used in the experimentation. Concentrations employed for the stripping tests were usually 250, 500 and 1000 mg/l of test compound or of calculated COD due to the compound. For a compound studied in the continuous flow and the batch pilot plants, separate stripping studies were conducted in each reactor under batch conditions unless the stripping study conducted in the batch pilot plant reactor indicated no stripping, little stripping or extremely rapid stripping. The purpose of these auxiliary studies was to determine whether the compound was strippable, not strippable or rapidly strippable, i.e. the aim was not to determine the stripping constants.

SECTION 5

RESULTS AND DISCUSSION

Although studies were performed concurrently in batch and continuous flow plants, results obtained with the two different types of pilot plants will be described separately.

PHASE I - BATCH PILOT PLANT STUDIES

As stated previously, in the work using batch pilot plants, one control unit was operated along with two test units. Each section below presents the data for the primary (pilot plant) and auxiliary studies for one compound. Auxiliary studies include stripping tests, measurements of rates of substrate removal and sludge growth, and, in most cases, analyses of samples for the specific test compound.

Naphthalene

The results shown in Figure 3 indicate that naphthalene at concentrations up to 50 mg/l in the feed (corresponding to 33 mg/l initial concentration) did not have a deleterious effect on the performance of the system in regard to removal of soluble COD. A single control was used for the naphthalene and toluene systems. Near the end of the experimental run on naphthalene, the toluene and naphthalene feeds were exchanged. The exchanging of the feeds did not appear to have any deleterious effect on the system.

The statistical analysis of the results (see Table 4) indicates that the soluble COD in the control was essentially the same as in the naphthalene unit. The biomass concentrations in control and test units were approximately the same and from these studies there was no indication that the naphthalene was used to synthesize biological solids. While the naphthalene concentrations employed were not very high, it should be noted that the theoretical COD of naphthalene is 3.0 mg/mg. The average measurable COD using the standard COD test was approximately 75% of the theoretical. In any case, it would not be expected that the metabolism of naphthalene would lead to significantly higher biological solids concentration. The important point to be made here is that the addition of naphthalene did not hamper the production of biological solids for a system growing essentially on sewage and an easily metabolized carbohydrate.

Stripping tests were run (see sample results shown in Figure 4) and the results indicate clearly that naphthalene is a highly strippable compound

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM O 'MAGE AR OUTSIDE DIMENSIO FOR TABL AND ILLU TRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-76)

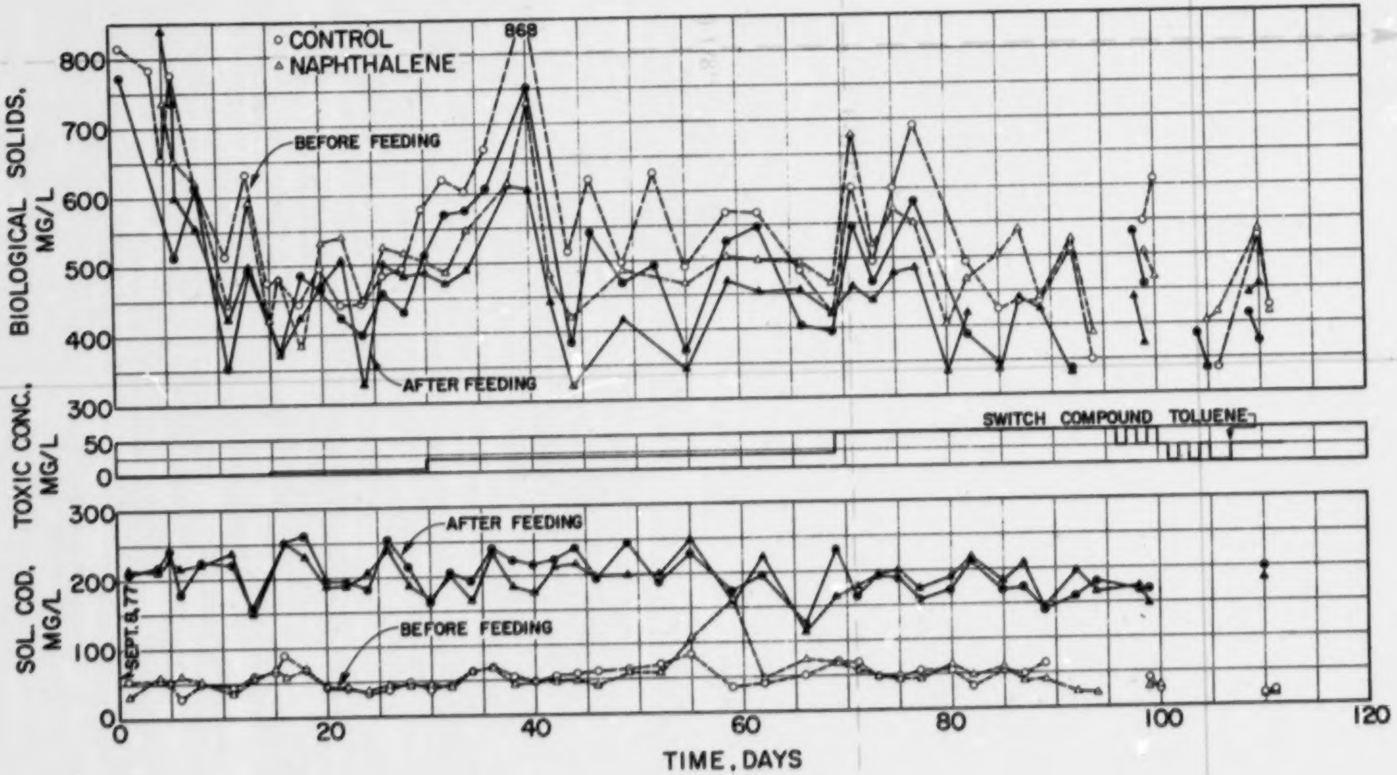

Figure 3. Operational results of batch control and naphthalene units.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

TABLE 4. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH NAPHTHALENE AND TOLUENE

Date	Parameter	CONTROL				NAPHTHALENE				TOLUENE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
9-9-77 to 9-23-77	N	8	7	8	5	8	7	6	6	8	7	8	7	No toxic compound added.
	X	52.1	207.1	658.0	549.6	52.5	210.9	578.0	609.3	49.1	207.7	755.5	655.4	
	σ	11.9	29.6	126.3	155.9	12.8	28.8	122.8	153.9	15.6	30.2	179.1	185.9	
	C.V.%	22.8	14.3	20.7	30.2	24.4	13.7	21.2	25.3	31.8	14.5	23.7	28.4	
	Range	28-68	157-241	476-816	352-772	32-70	149-237	420-736	424-840	24-72	145-236	476-956	404-920	
9-24-77 to 10-8-77	N	8	8	8	8	8	8	8	8	8	8	8	8	5 mg/l toxic compound added.
	X	50.1	215.6	483.0	443.9	48.1	207.6	491.2	446.8	41.9	199.4	551.6	481.5	
	σ	20.0	37.6	45.1	46.1	10.6	30.6	52.8	65.9	8.4	31.6	47.1	59.2	
	C.V.%	40.0	17.4	9.3	10.4	22.0	14.7	10.8	14.8	20.0	15.8	8.5	12.3	
	Range	34-92	163-263	444-580	372-512	38-70	167-253	384-540	328-508	32-60	163-249	480-624	380-593	
10-9-77 to 11-16-77	N	15	15	13	13	15	15	12	12	15	15	13	13	20 mg/l toxic compound
	X	58.1	208.7	580.3	510.7	65.2	189.4	516.9	459.2	49.8	188.8	557.9	471.5	
	σ	12.7	32.1	116.7	108.3	31.5	32.9	82.1	86.3	15.2	30.2	118.3	121.4	
	C.V.%	21.9	15.4	20.1	21.2	48.3	17.4	15.9	18.8	30.5	16.0	21.2	25.7	
	Range	36-84	124-247	420-868	370-752	41-161	116-249	420-730	322-612	22-74	161-226	410-848	334-798	
11-17-77 to 12-12-77	N	11	11	10	9	11	11	11	11	11	11	10	10	50 mg/l toxic compound added.
	X	46.8	173.3	502.5	436.3	44.1	187.2	508.0	397.4	43.5	183.4	501.7	409.1	
	σ	15.6	19.9	102.1	99.7	13.8	19.1	82.5	65.5	13.4	19.8	106.3	75.9	
	C.V.%	33.3	11.5	20.3	22.8	31.3	10.2	16.2	16.5	30.8	10.8	21.2	18.6	
	Range	20-68	140-213	348-690	324-580	20-63	154-217	388-680	316-485	20-64	154-233	316-720	320-520	
12-13-77 to 12-23-77	N	2	2	4	4	2	2	4	4	2	2	4	4	Cyclic changes.
	X	31.5	167.0	449.5	405	28	159	448	384	24.0	155.0	495.0	421.3	
	σ	12.0	0	150.9	108.6	0	17.0	46.5	43.2	5.7	28.3	37.7	22.8	
	C.V.%	38.1	0	33.6	26.8	0	10.7	10.4	11.2	23.8	18.3	7.6	5.4	
	Range	23-40	167-167	306-608	296-532	28-28	147-171	404-504	336-440	20-28	135-175	460-540	404-452	
12-24-77 to 12-31-77	N	2	1	2	2	2	1	2	2	2	1	2	2	Switching of toxic compounds.
	X	18	199	474.0	392.0	20	183	476	450	16.0	211.0	568.0	532.0	
	σ	2.8	--	70.7	28.3	0	--	84.8	8.5	0	--	0	28.3	
	C.V.%	15.0	--	14.9	7.2	0	--	17.8	1.9	0	--	0	5.3	
	Range	16-20	--	424-524	372-412	20-20	--	416-536	444-456	16-16	--	568-568	512-552	

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

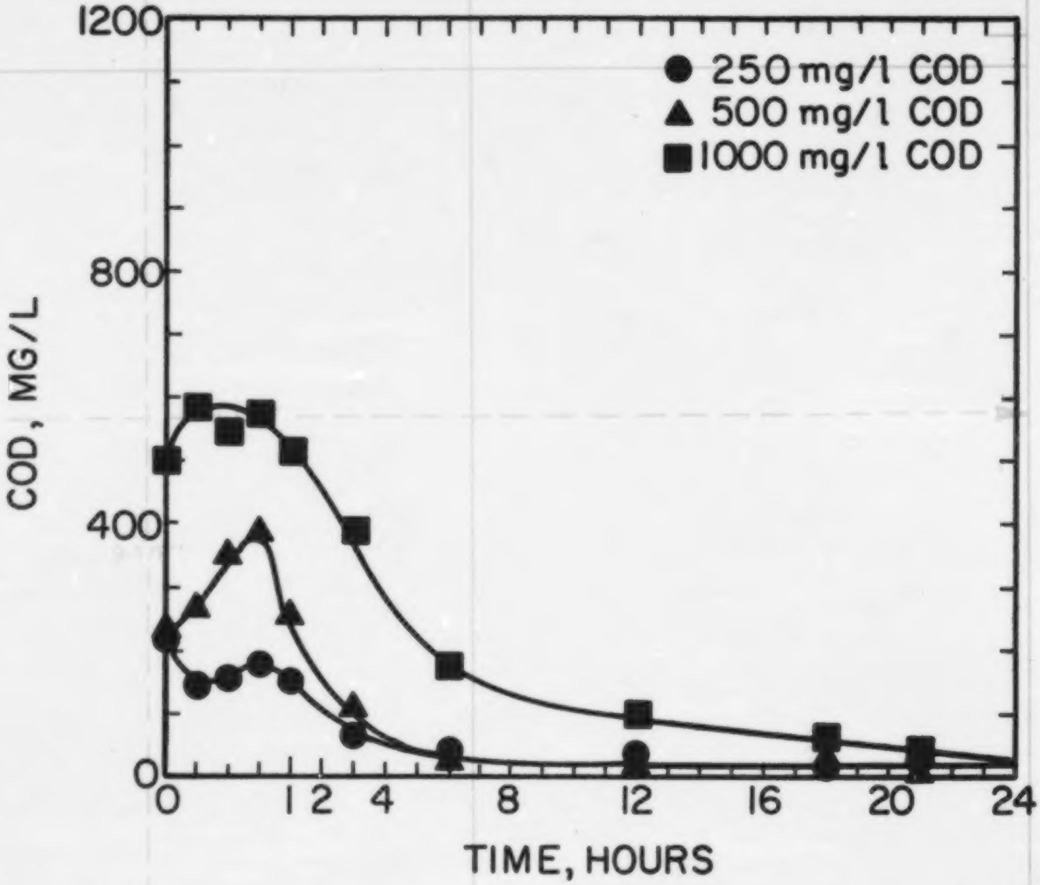

Figure 4. Stripping of naphthalene in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

at the air flow employed in these batch studies. The relative insolubility of naphthalene accounts for the rather erratic results shown in the early parts of the study when the naphthalene concentration was rather high. For example, note the results during the first hour for the unit dosed with 1000 mg/l naphthalene COD.

Several individual batch growth and COD removal rate studies were made during the course of these studies on naphthalene and an example of the time course of growth and COD removal for two concentrations of naphthalene is shown in Figure 5. It is apparent from these results that naphthalene had little or no effect on the course of COD removal or growth.

Toluene

The results shown in Figure 6 indicate that toluene at concentrations up to 50 mg/l in the feed can be expected to exert little or no effect on the efficiency of substrate removal. The statistical analyses of the batch pilot plant results (see Table 4) indicate that the COD removal in the toluene unit was slightly greater than in the control and there were no large differences in the variability of the results, as adjudged by the coefficient of variation (C.V.). Only slightly higher biological solids concentrations were developed in the toluene unit as compared to the control. The results of stripping tests indicated that toluene strips at an extremely fast rate (see Figure 7).

A number of metabolic rate studies were made and sample results are shown in Figure 8. It is seen that there is some evidence to indicate that toluene at either concentration employed (20 or 33 mg/l) caused a slight retardation in the rate of COD removal.

No analyses for toluene were made during the period of study.

Hexachlorobenzene

Figure 9 indicates that hexachlorobenzene at varying concentrations up to 50 mg/l in the feed did not cause a deleterious effect on the performance of the system with regard to soluble COD removal or solids production. When the priority pollutant in the feed was switched from hexachlorobenze to benzene, there was no apparent effect on the system. The statistical analysis of the results (Table 5) indicates that the test unit and the control exhibited similar performance.

Hexachlorobenzene is not soluble in water and does not respond to the standard COD test; therefore, stripping studies were not performed. Figure 10 shows that 50 mg/l of hexachlorobenzene in the feed had no effect on the rate of biomass growth or COD removal. The residual COD in the hexachlorobenzene unit was higher than in the control; however, this result would not appear to be a typical effect since the daily results for the batch unit show the test and control unit to have the same soluble residual COD.

EPA-287 (Cin.)
(4-76)

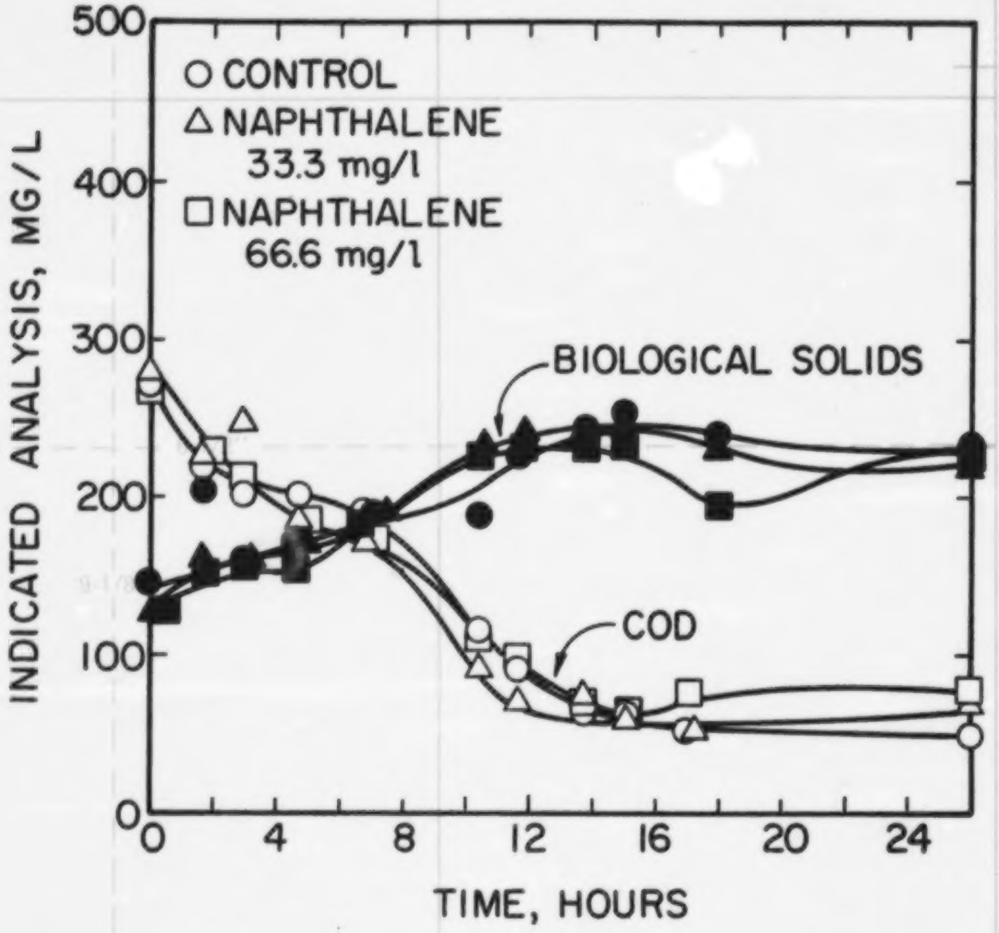

Figure 5. Growth and COD removal of batch naphthalene unit, dosage=50 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

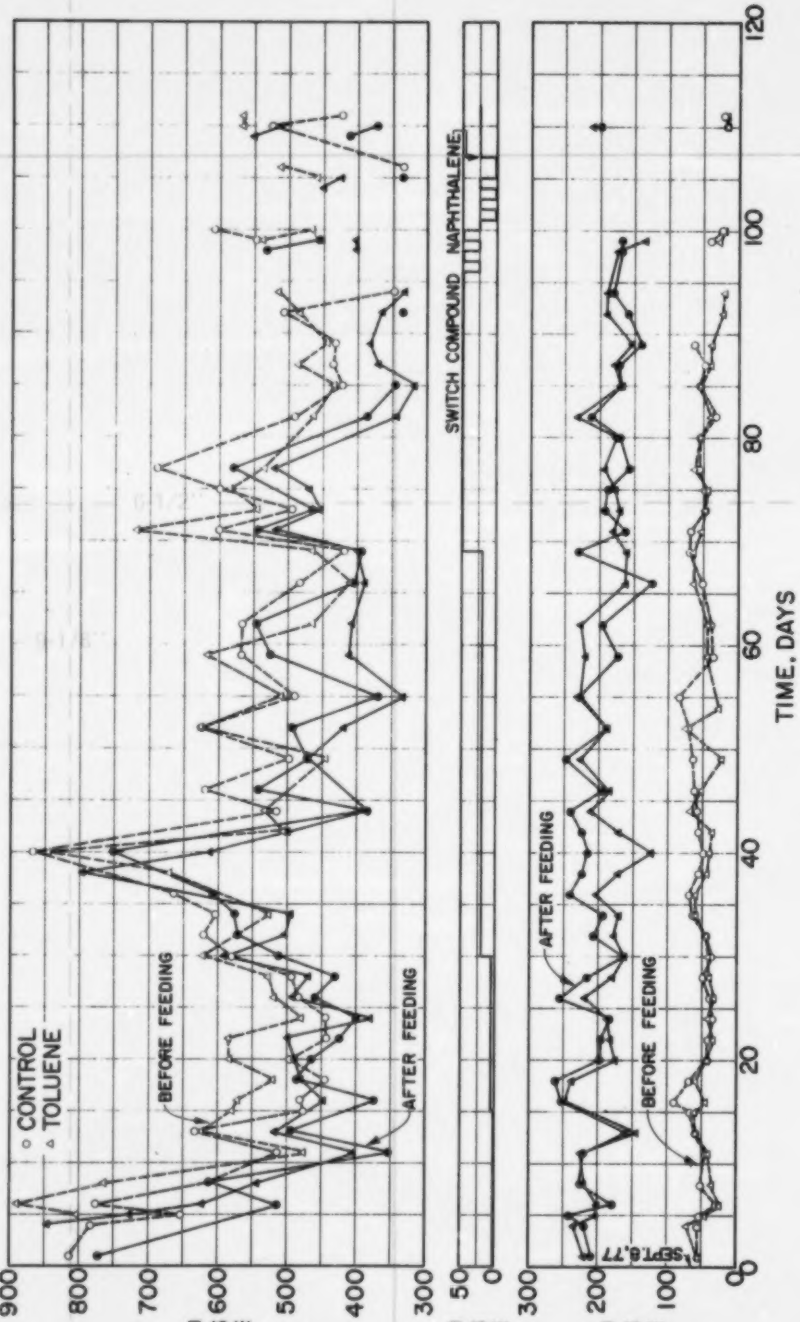

Figure 6. Operational results of batch control and toluene units.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

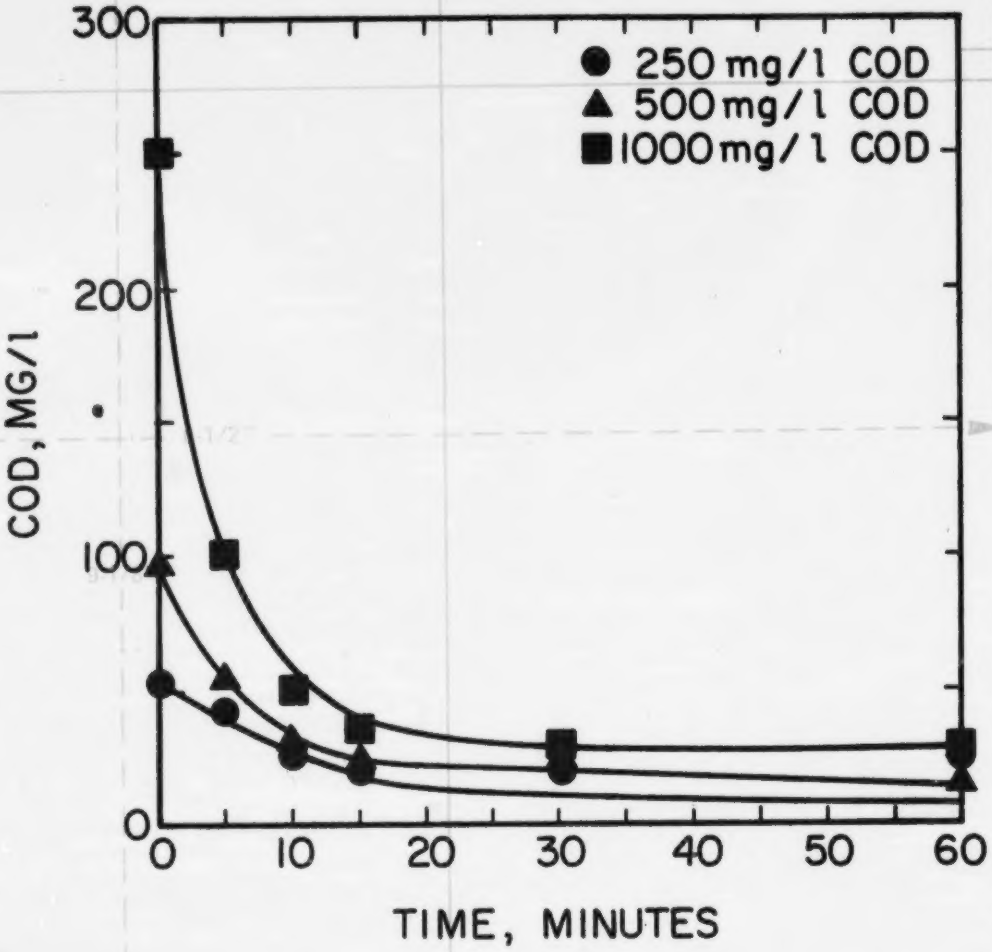

Figure 7. Stripping of toluene in the batch growth reactor.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

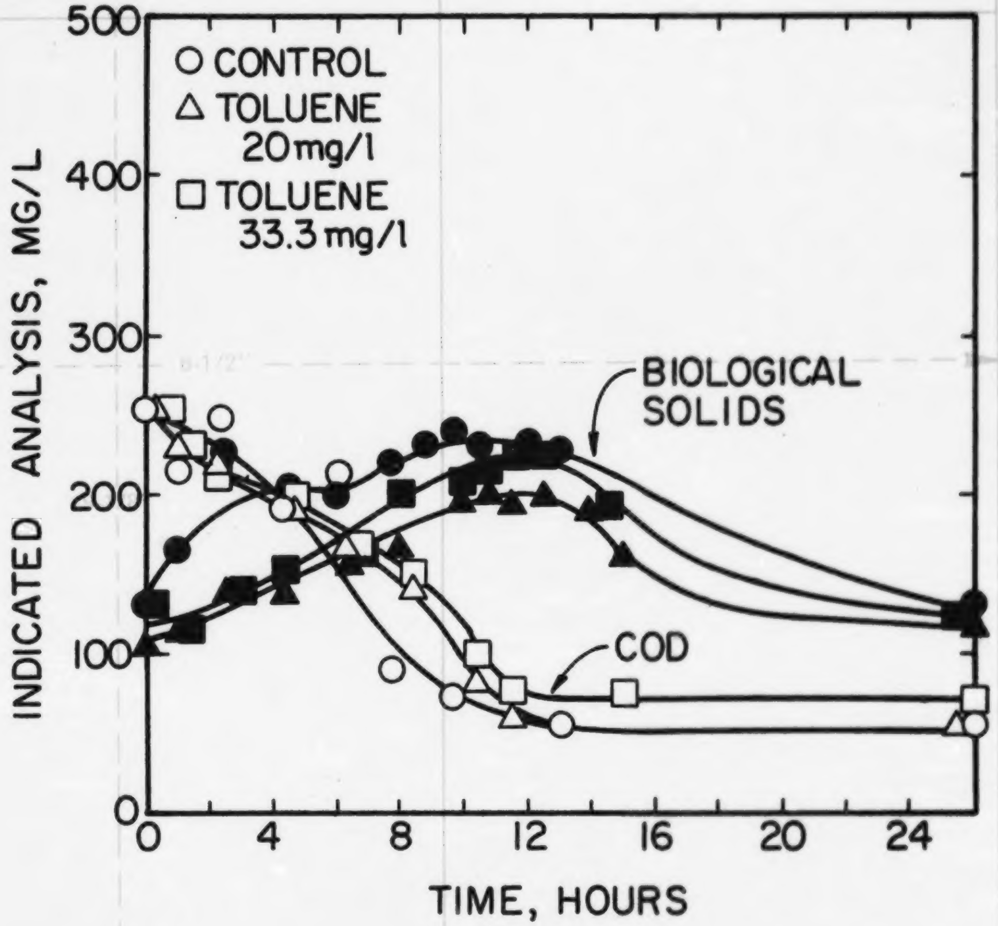

Figure 8. Growth and COD removal of batch toluene unit, dosage=20 mg/1.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
8-1/2"

EPA-287 (Cin.)
(4-76)

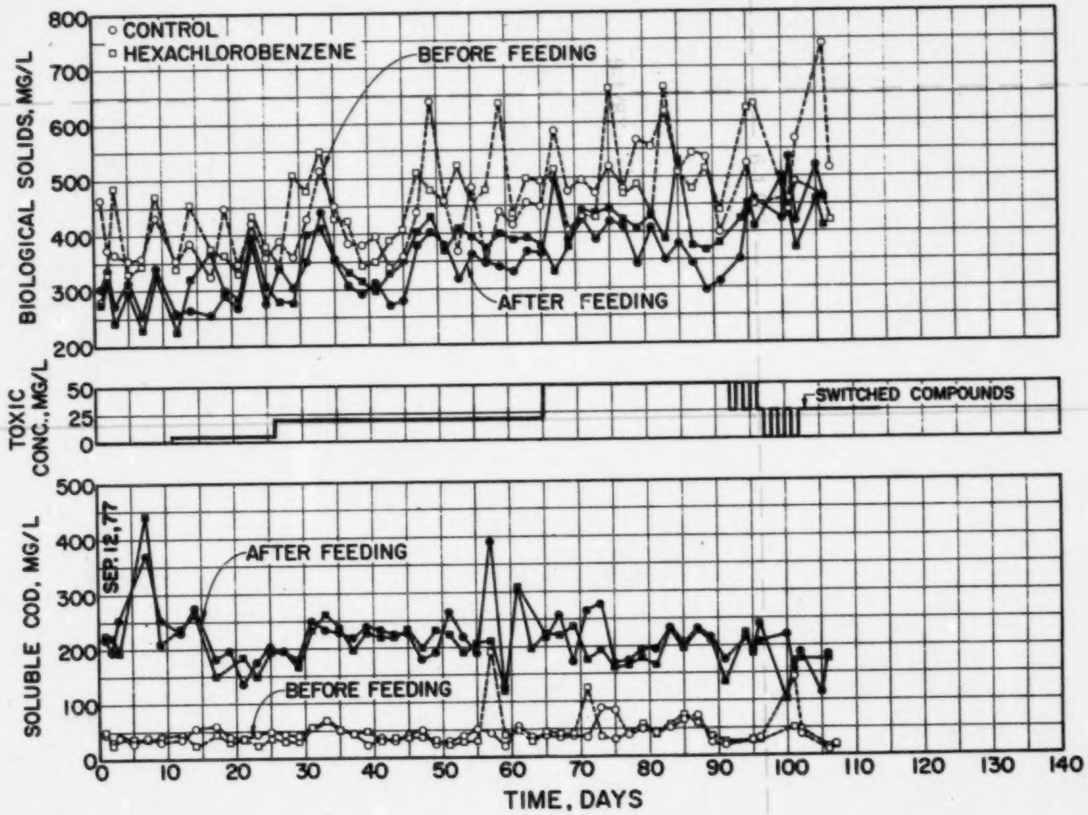

Figure 9. Operational results of batch control and hexachlorobenzene units.

EPA-287 (Cin.)
(4-76)

TABLE 5. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH HEXACHLOROBENZENE AND BENZENE

Date	Parameter	CONTROL				HEXACHLOROBENZENE				BENZENE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
9-13-77 to 9-23-77	N	6	5	6	6	6	5	6	6	6	5	6	6	No toxic compound added.
	X	36.7	257.4	391.3	304.3	38.0	258.4	374.0	281.7	38.0	242.2	386.3	289.3	
	σ	6.5	67.2	45.6	34.6	7.8	103.4	84.4	40.0	6.2	55.9	51.6	31.8	
	C.V.%	17.7	26.1	11.6	11.4	20.5	40.0	22.6	14.2	16.3	23.1	13.4	11.0	
	Range	28-46	194-369	354-464	254-340	26-50	193-442	280-486	230-326	26-44	206-341	334-458	234-320	
9-24-77 to 10-8-77	N	7	7	7	7	7	6	7	7	7	7	7	7	5 mg/l toxic compound added.
	X	45.9	199.4	376.9	286.1	33.9	195.7	382.6	315.1	33.0	184.7	362.3	305.4	
	σ	9.5	43.5	44.4	44.7	8.6	46.1	46.6	55.6	7.5	41.2	21.4	44.8	
	C.V.%	20.7	21.8	11.8	15.6	25.5	23.5	12.2	17.6	22.6	22.3	5.9	14.7	
	Range	36-60	136-274	324-448	256-384	24-44	184-262	330-456	226-396	24-44	112-233	326-394	246-362	
10-9-77 to 11-16-77	N	19	18	20	20	19	18	19	19	19	19	17	17	20 mg/l toxic compound added.
	X	42.6	232.4	422.9	345.6	39.6	221.3	457.8	369.5	40.0	219.4	462.4	404.2	
	σ	11.4	50.5	73.2	41.2	11.1	30.5	74.6	42.3	10.3	55.3	53.2	47.8	
	C.V.%	26.8	21.7	17.3	11.9	28.0	13.8	16.3	11.4	25.8	25.2	11.5	11.8	
	Range	23-68	179-392	304-640	272-440	24-68	167-308	342-638	280-432	20-64	134-396	328-552	284-480	
11-17-77 to 12-12-77	N	13	13	13	13	13	13	10	10	12	13	9	9	50 mg/l toxic compound added.
	X	50.5	212.5	520.0	381.8	51.7	192.3	507.6	392.8	46.2	185.0	507.6	383.6	
	σ	21.7	37.3	57.4	53.2	26.2	31.6	88.5	34.0	10.7	33.5	50.1	71.4	
	C.V.%	43.0	17.6	11.0	13.9	50.7	16.4	17.4	8.7	23.2	18.1	9.9	18.6	
	Range	20-88	170-265	400-620	296-496	24-126	135-237	408-664	332-444	24-61	118-238	432-576	272-472	
12-13-77 to 12-24-77	N	5	4	4	3	4	5	4	4	4	4	4	4	Cyclic changes.
	X	26.2	185.8	501.0	438.7	38.5	199.2	547.0	417.0	45.5	199.5	509.0	394	
	σ	10.5	20.9	55.1	20.1	12.2	30.1	96.0	34.2	13.4	14.1	25.0	14.8	
	C.V.%	40.1	11.2	11.0	4.6	31.7	15.1	17.6	8.2	29.4	7.1	4.9	3.8	
	Range	28-39	157-207	452-568	420-460	28-51	171-239	440-632	372-452	28-59	184-215	484-536	376-408	
12-25-77 to 12-31-77	N	2	1	2	1	2	1	2	1	2	1	2	1	Switching of toxic compounds.
	X	16.0	183	628.0	464	16	175	442.0	412	16	187	542	392	
	σ	5.7	--	158.4	--	0	--	31.1	--	5.7	--	59.4	--	
	C.V.%	35.6	--	25.2	--	0	--	7.0	--	35.6	--	11.0	--	
	Range	12-20	--	516-740	--	16-16	--	420-464	--	12-20	--	500-584	--	

EPA-287 (Cin.)
(4-76)

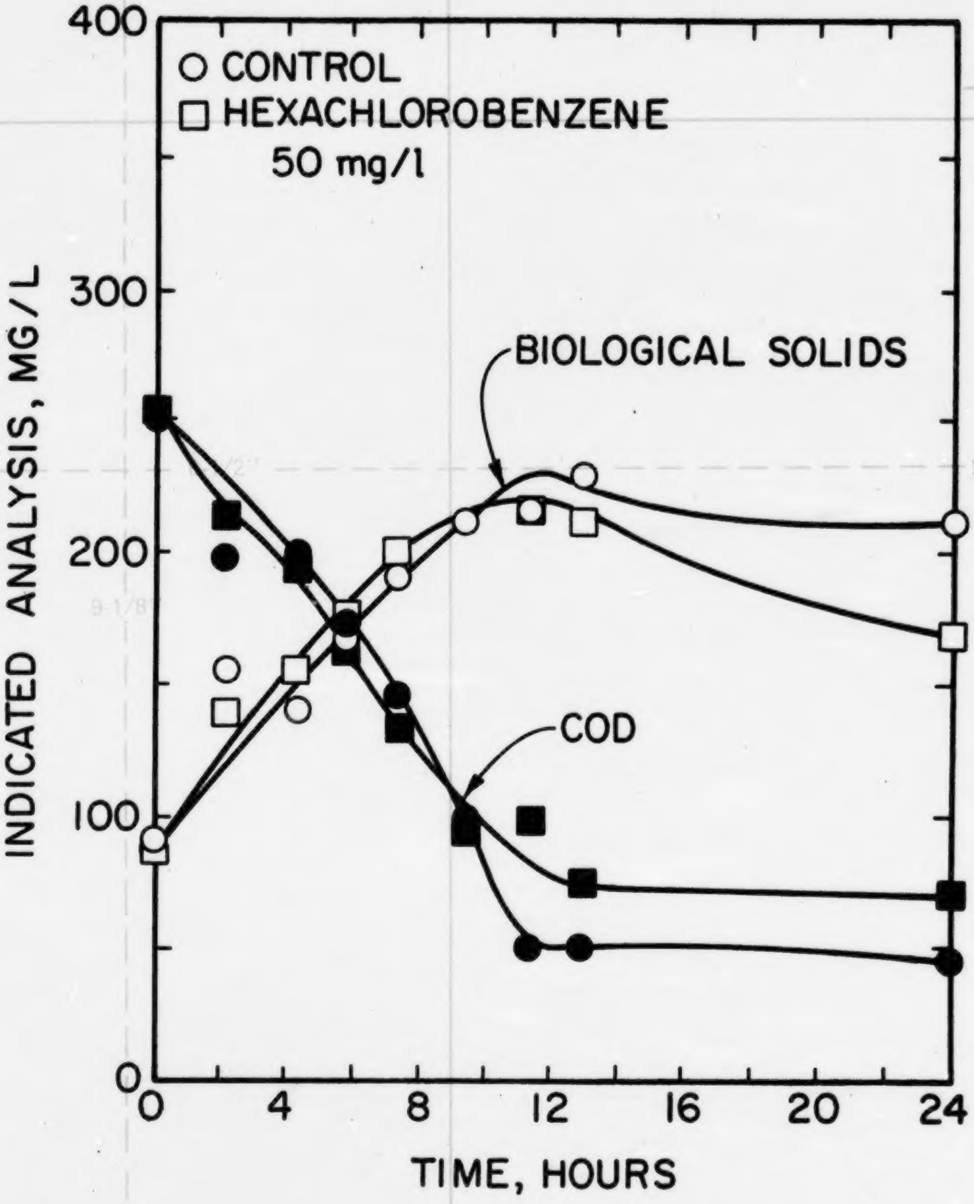

Figure 10. Growth and COD removal of hexachlorobenzene unit, dosage=50 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Benzene

Figure 11 shows that concentrations of benzene in the feed up to 50 mg/l had no adverse effects upon the performance of the system. This conclusion is enforced by inspection of the statistical analysis of the data shown in Table 5. Benzene is a highly strippable compound as seen in the sample stripping tests made during this run (Figure 12).

Figure 13 shows the comparative performance of the control system and the test unit after dosage with 20 mg/l of benzene. Biomass concentration did not reach the same level in the benzene unit as it did in the control. However, in subsequent batch studies at dosage levels of 50 mg/l of benzene, the biomass concentrations in both units were the same. Thus, the lower level shown in this figure does not appear to be a result typical of the effects of benzene. The limited amount of data taken on suspended solids concentration in the supernatant after 1 hour of settling indicated no deleterious effects due to benzene at the concentrations herein employed.

Phenol

The results for long-term batch feeding of phenol at varying concentrations are shown in Figure 14 and it is seen that the mixed liquor biological solids concentration was consistently lower in the unit which received phenol than in the control. Also, shortly after receiving phenol dosage the soluble COD in the supernatant became slightly higher than in the control unit. After nearly 70 days of operations, during which the phenol concentration was increased in steps to 50 mg/l in the feed, biomass concentration in the phenol reactor approached that in the control. From the statistical summary shown in Table 6, it is noted that the biological solids in the unit which was dosed with phenol was lower than in the control before dosage began. Thus, the lower amount of solids during the 5 and 25 mg/l dosages is not necessarily due to an inhibitory effect of phenol. The fact that the biomass concentration was essentially the same in the control and the phenol-dosed unit during the 50 mg/l dosage indicates that the unit acclimated to the phenol. This conclusion is substantiated by the fact that the soluble COD in the supernatant was only a few mg higher in the phenol unit than in the control unit.

Phenol is not subject to stripping as is confirmed in Figure 15. The batch growth study shown in Figure 16 shows that phenol did not interfere with the course of growth and substrate removal at dosage levels of 25 and 50 mg/l in the feed. It would appear from these results that the rather significant lysis or release of cellular COD which occurred in the control after the substrate removal and growth period (approximately 9 hours-Fig. 16) was attenuated by the presence of phenol in the system and the attenuation was related to the phenol concentration.

The presence of phenol in the feed had no apparent effect on settleability or the concentration of suspended solids in the supernatant after quiescent settling. The results of a few analyses for phenol in the supernatant at the end of the feeding period indicated that for the 20 mg/l

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

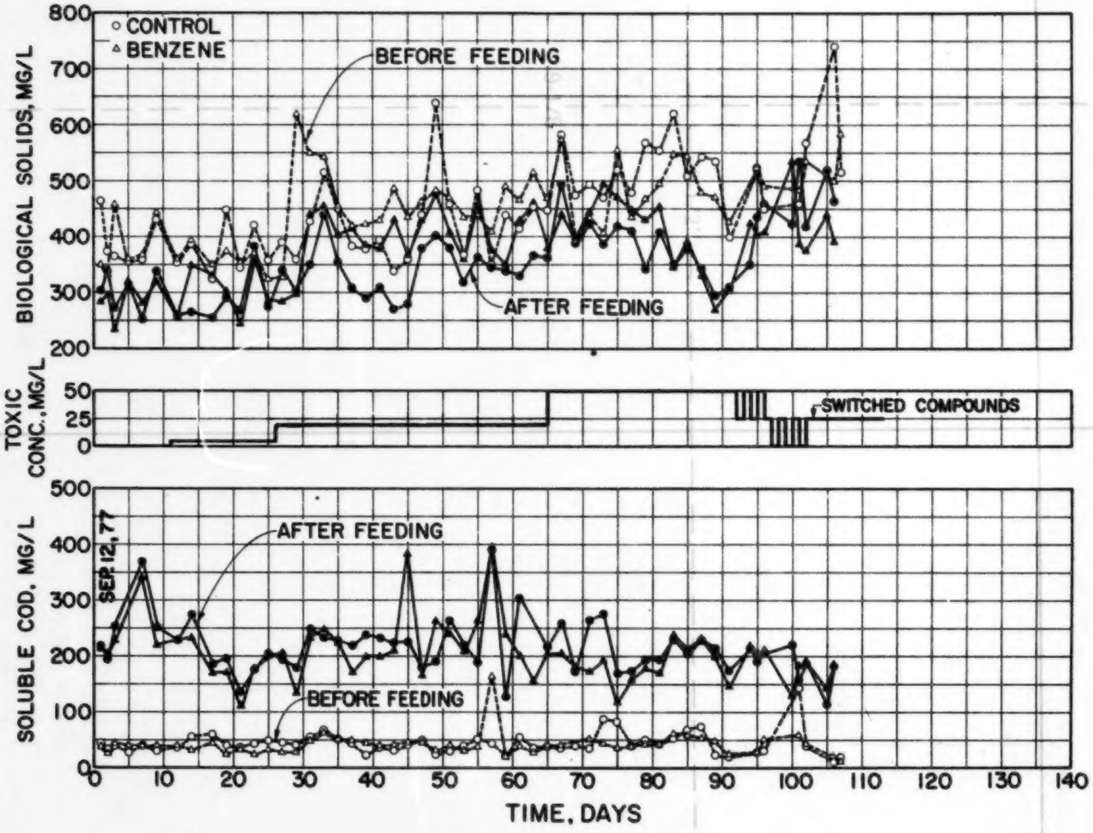

Figure 11. Operational results of batch control and benzene units.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

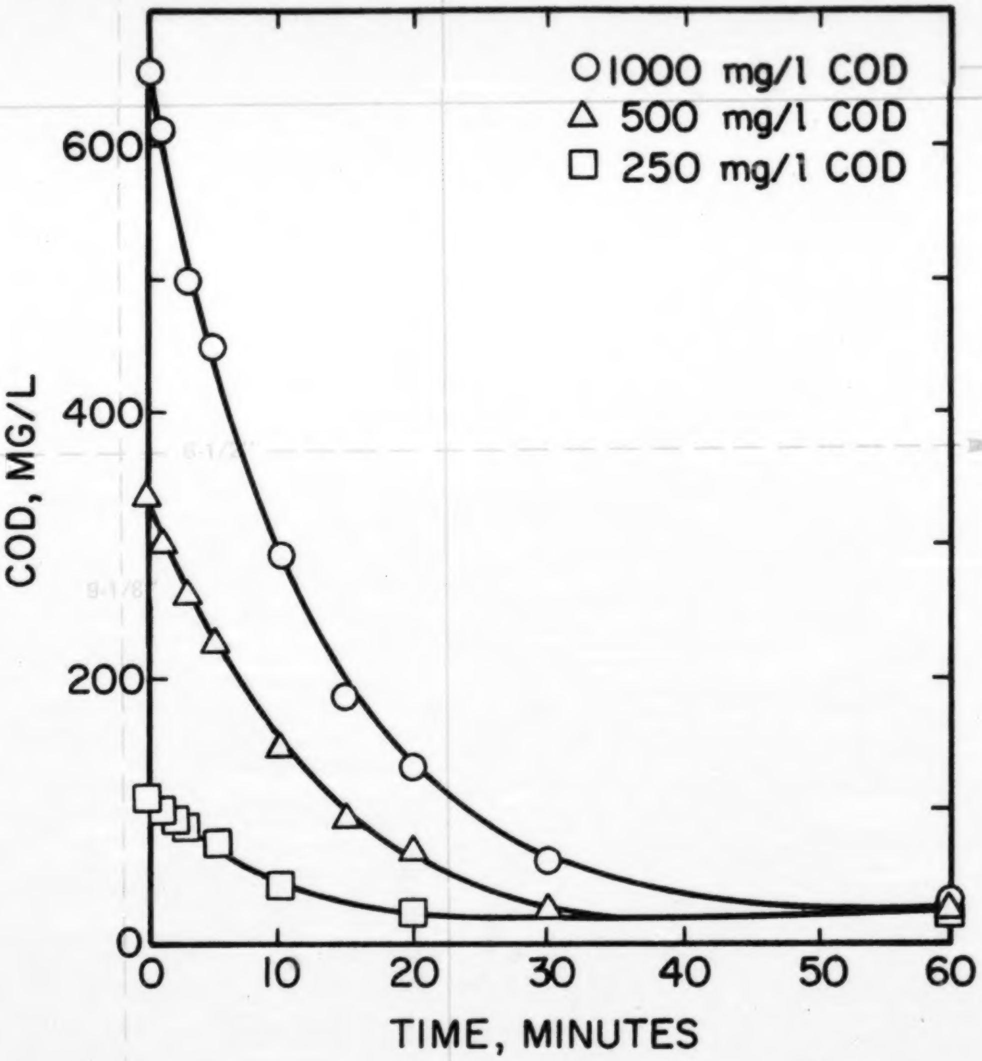

Figure 12. Stripping of benzene in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

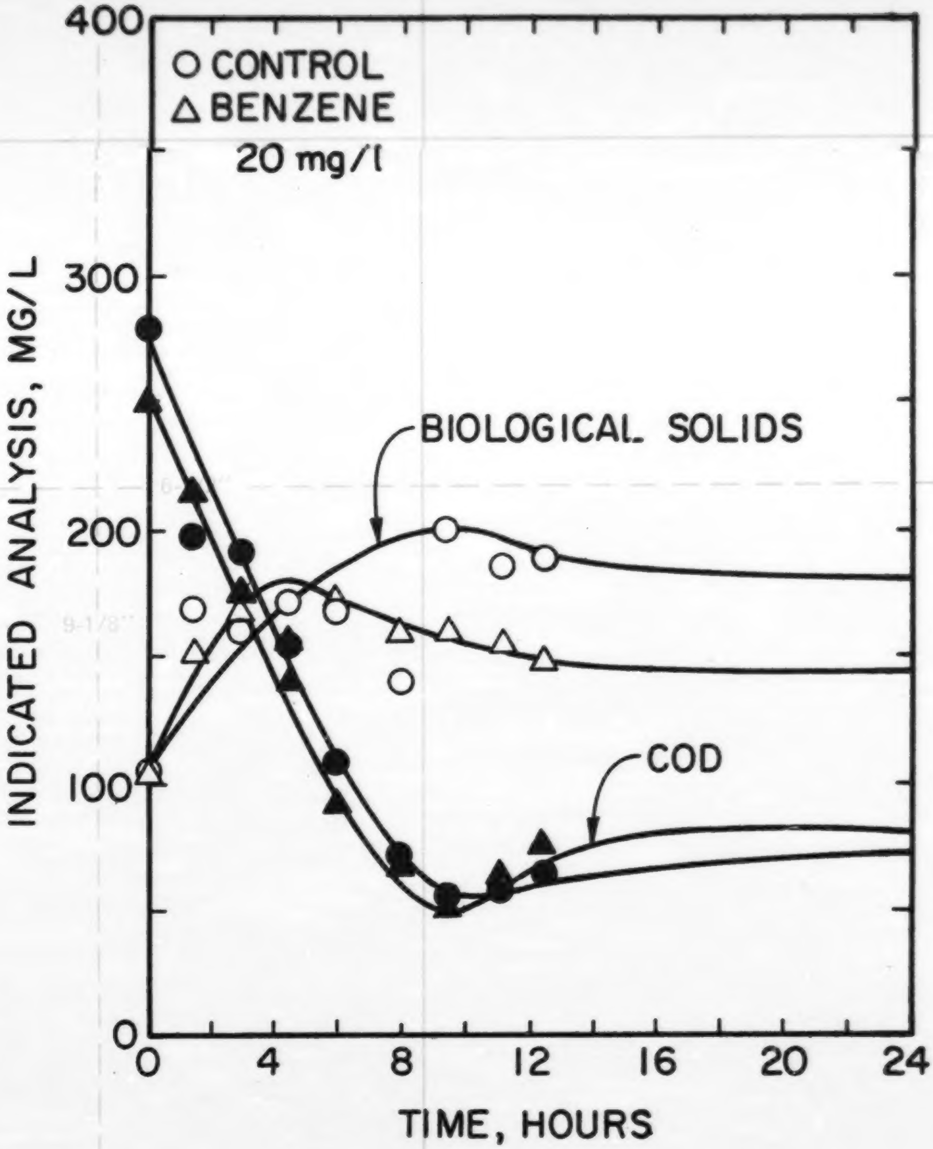

Figure 13. Growth and COD removal of batch benzene unit, dosage=20 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

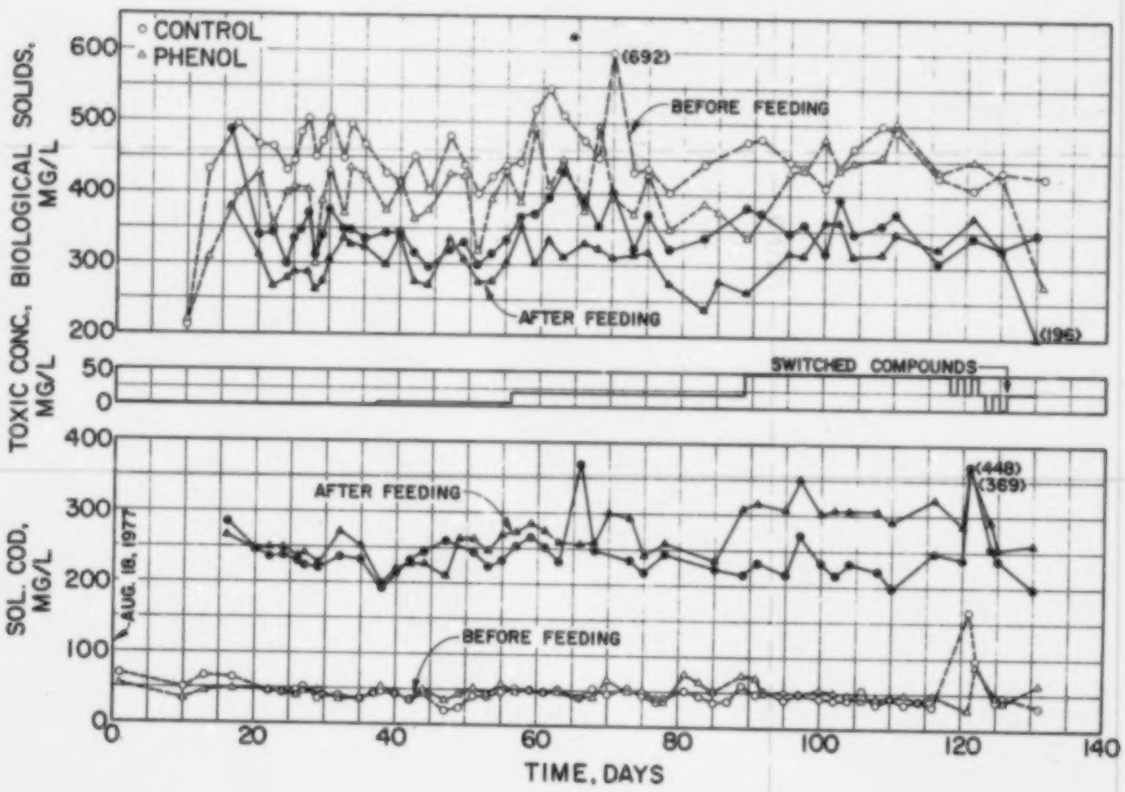

Figure 14. Operational results of batch control and phenol units.

TABLE 6. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH PHENOL AND PENTRACHLOROPHENOL

Date	Parameter	CONTROL				PHENOL				PENTACHLOROPHENOL				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
9-9-77 to 9-24-77	N	8	7	11	11	8	7	10	10	8	7	9	9	No toxic compound added.
	X	43.2	231.3	469.8	341.8	43.0	247.9	392.0	296.0	42.3	236.4	402.2	308.4	
	σ	5.6	6.6	24.8	22.2	5.1	13.9	41.1	26.1	7.7	9.5	54.9	50.1	
	C.V.%	13.0	2.8	5.3	9.2	11.9	5.6	10.5	8.8	18.2	4.0	13.6	16.2	
	Range	36-52	221-238	432-504	300-376	36-48	229-273	300-436	264-336	32-52	221-252	304-456	228-364	
9-25-77 to 10-8-77	N	7	6	7	7	7	7	7	7	7	6	7	7	5 mg/l toxic compound added.
	X	36.3	231.0	431.4	321.7	45.3	230.9	386.3	301.1	57.4	253.5	290.3	228.6	
	σ	10.4	24.3	28.4	19.4	7.4	24.8	39.0	28.5	9.9	22.7	43.3	26.2	
	C.V.%	28.6	10.5	6.6	6.0	16.3	10.7	10.1	9.5	17.2	9.0	14.9	11.5	
	Range	20-46	193-260	400-480	296-344	36-54	199-264	320-428	272-340	44-69	224-280	244-380	200-280	
10-9-77 to 11-16-77	N	18	13	14	14	17	14	15	15	18	15	15	15	20 mg/l toxic compound added.
	X	46.5	247.5	478.6	365.4	52.4	269.9	405.9	303.5	70.9	296.3	279.5	212.8	
	σ	6.9	39.7	73.6	34.5	11.7	22.3	46.0	30.8	12.7	45.0	40.8	34.4	
	C.V.%	14.8	16.0	15.4	9.4	2.2	8.3	11.3	10.2	17.9	15.2	14.6	16.2	
	Range	36-60	217-370	404-692	316-432	36-74	242-310	288-492	240-356	49-91	256-393	216-324	268-152	
11-17-77 to 12-12-77	N	13	9	9	9	13	9	8	8	13	9	9	9	50 mg/l toxic compound added.
	X	42.5	230.7	456.4	354.7	48.9	313.8	453.5	334.5	71.5	283.0	327.1	240.9	
	σ	6.8	21.0	30.1	27.7	8.3	17.0	25.8	20.9	19.4	21.6	49.7	37.2	
	C.V.%	16.0	9.1	6.6	7.8	17.0	5.4	5.7	6.2	27.1	7.6	15.2	15.4	
	Range	32-55	199-273	412-500	308-396	40-72	293-353	360-504	316-364	55-109	262-302	236-388	164-284	
12-13-77 to 12-23-77	N	4	4	2	2	4	4	2	2	4	4	2	2	Cyclic changes.
	X	87.8	295.5	424.0	336.0	51.0	301.5	440.0	344.0	81.8	287.8	298.0	226.0	
	σ	58.9	101.9	17.0	11.3	27.1	48.2	17.0	39.6	21.8	28.4	99.0	48.1	
	C.V.%	67.1	34.5	4.0	3.4	53.1	16.0	3.9	11.6	26.6	9.9	33.2	21.3	
	Range	39-167	239-448	412-436	328-344	28-90	255-369	428-452	316-372	67-114	267-329	228-368	192-260	
12-24-77 to 12-31-77	N	1	1	1	1	1	1	1	1	1	1	1	1	Switching of toxic compounds.
	X	32	199	428	348	64	262	276	196	44	274	404	304	
	σ	--	--	--	--	--	--	--	--	--	--	--	--	
	C.V.%	--	--	--	--	--	--	--	--	--	--	--	--	
	Range	--	--	--	--	--	--	--	--	--	--	--	--	

EPA-287 (Cin.)
(4-76)

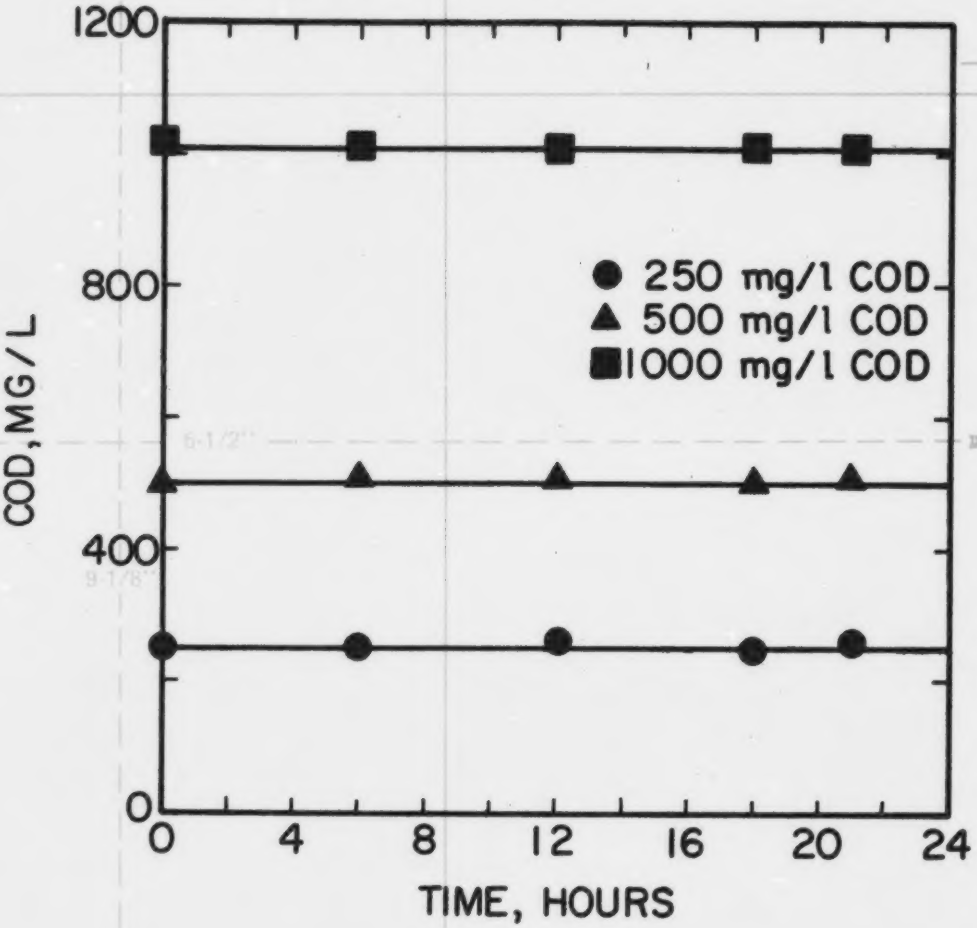

Figure 15. Stripping of phenol in the batch growth reactor.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

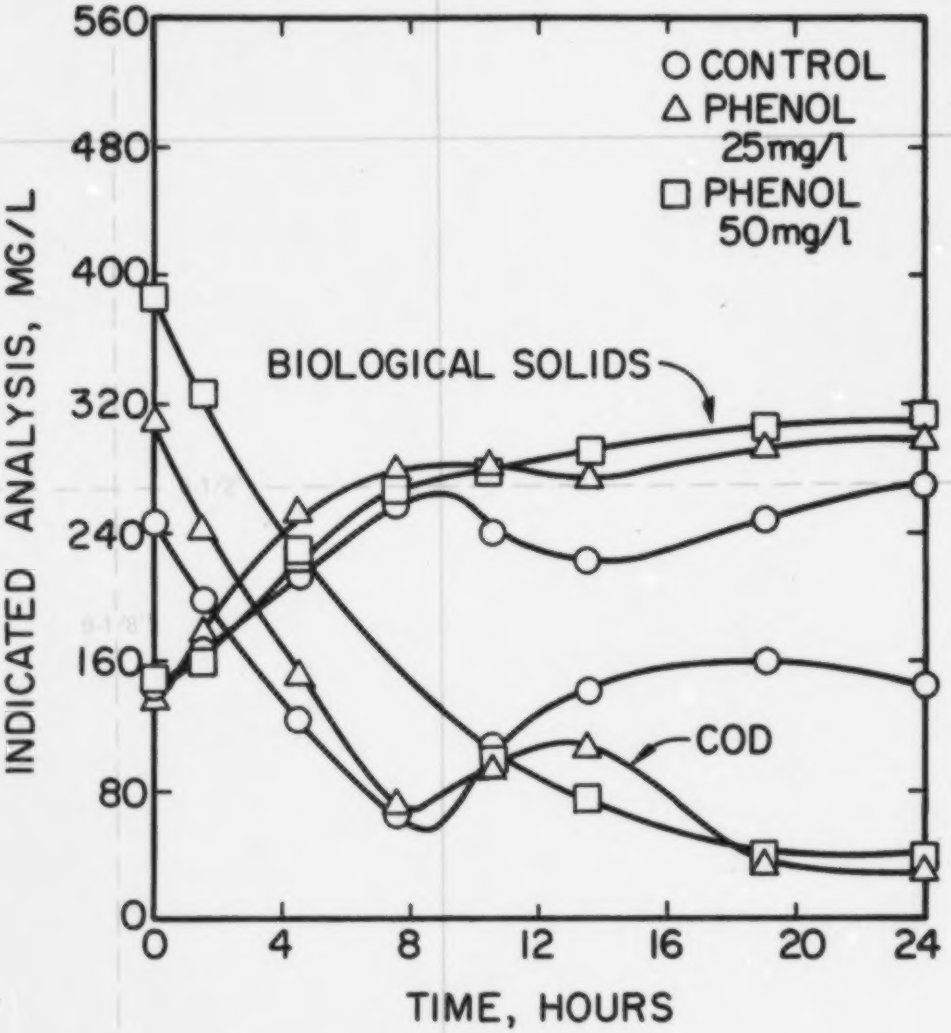

Figure 16. Growth and COD removal of batch phenol unit, dosage=50 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

dosage level in the feed, the phenol was removed during the 23-hour aeration period. Late in the experimental period, the color of the sludge turned from brown to a white-grey in response to changing the dose from phenol to pentachlorophenol.

Pentachlorophenol

Figure 17 shows the comparative performance of a control unit and a unit dosed with increasingly higher concentrations of pentachlorophenol. The biomass concentration in the unit receiving pentachlorophenol was considerably lower than in the control unit. Unlike the unit which received phenol, the one dosed with pentachlorophenol did not eventually attain the same mixed liquor solids concentration as the control. Also, it is apparent from the figure that the soluble COD in the supernatant was higher than in the phenol unit or the control unit. The statistical analyses shown in Table 6 indicate a considerably higher average concentration of soluble COD in the pentachlorophenol unit than in the control. Even though the unit receiving pentachlorophenol contained a lower concentration of mixed liquor suspended solids before dosing began, there is little doubt that at all dosages the presence of pentachlorophenol served to depress the biological solids concentration in the system. Pentachlorophenol is known to be an uncoupler of oxidative phosphorylation and its effect in reducing the cell yield could provide an explanation for the lower mixed liquor solids concentrations. Figure 18 indicates that pentachlorophenol was not strippable under the condition of these experimentations.

The batch growth and substrate removal rate studies shown in Figure 19 indicate that pentachlorophenol at concentrations of 30 and 50 mg/l had a slight retarding effect on substrate removal. During settling tests it was noted that the presence of pentachlorophenol caused an increase in suspended solids concentration of the supernatant.

Nitrobenzene

Comparison of the performance of the control unit and one dosed with varying concentrations of nitrobenze is shown in Figure 20. It can be seen that at times the COD of the sewage fed to the unit was abnormally high. Generally, at these times, the unit exhibited a considerable amount of foaming, sometimes leading to loss of some biological solids. There is no readily apparent explanation for the abnormally high COD of the municipal sewage from Stillwater on these dates. However, it is probably due to slug or semi-slug doses of waste from one of the industrial concerns in the municipality. In general, the soluble COD at the end of the feeding period was somewhat higher in the nitrobenzene unit than it was in the control unit.

The addition of the test compound caused a change in predominance leading to fewer protozoa in the system and to the production of more loosely bound floc particles. Settling tests, periodically performed, indicated that the suspended solids in the supernatant of the nitrobenzene unit was somewhat higher than that in the control unit. The statistical analysis

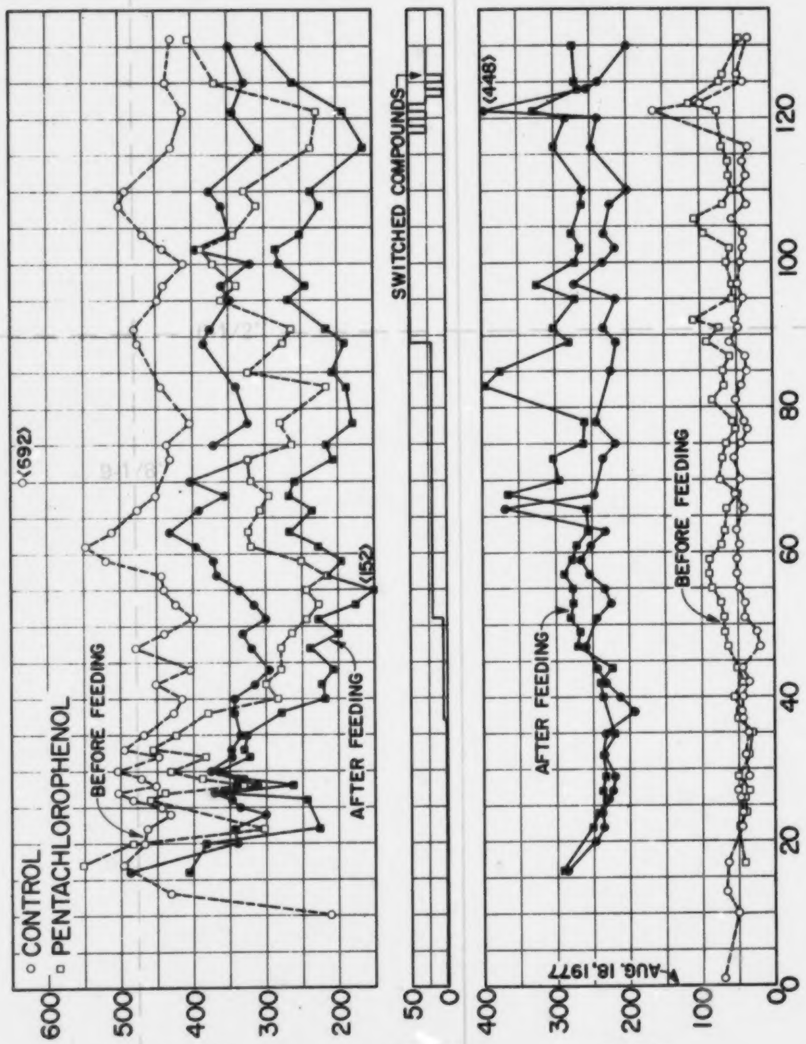

Figure 17. Operational results of batch control and pentachlorophenol units.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

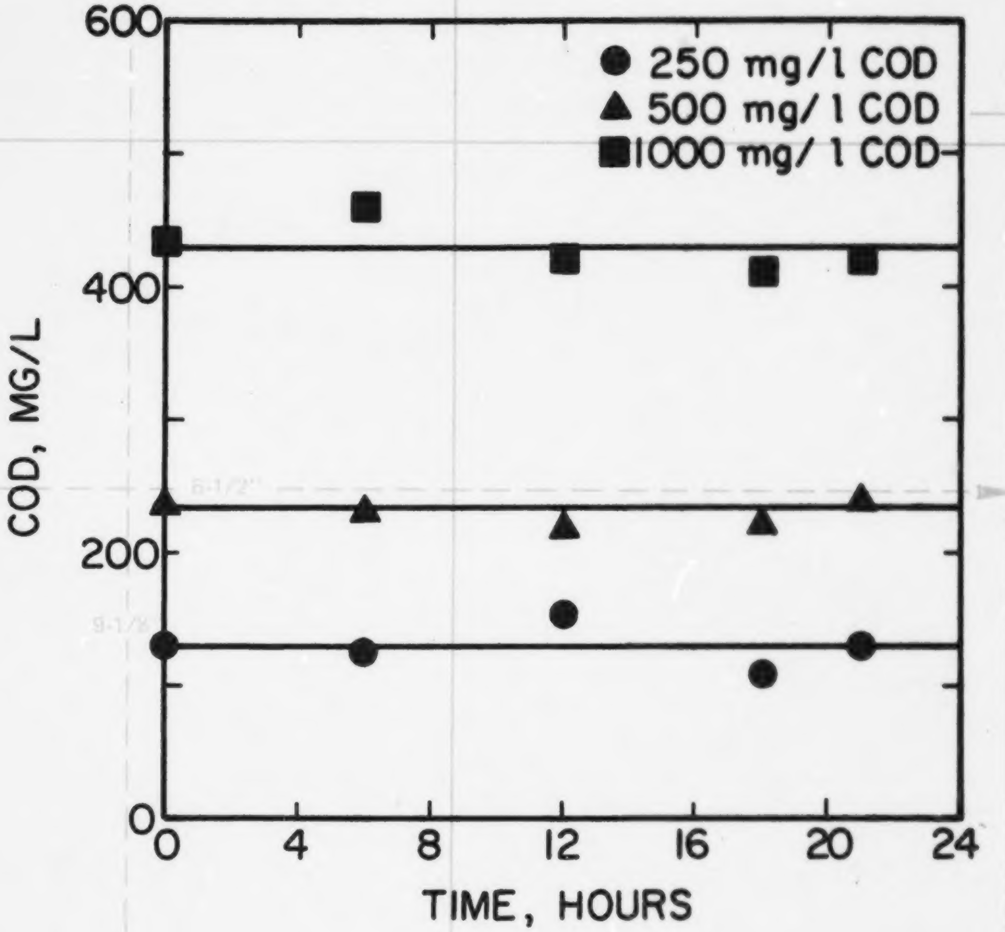

Figure 18. Stripping of pentachlorophenol in batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

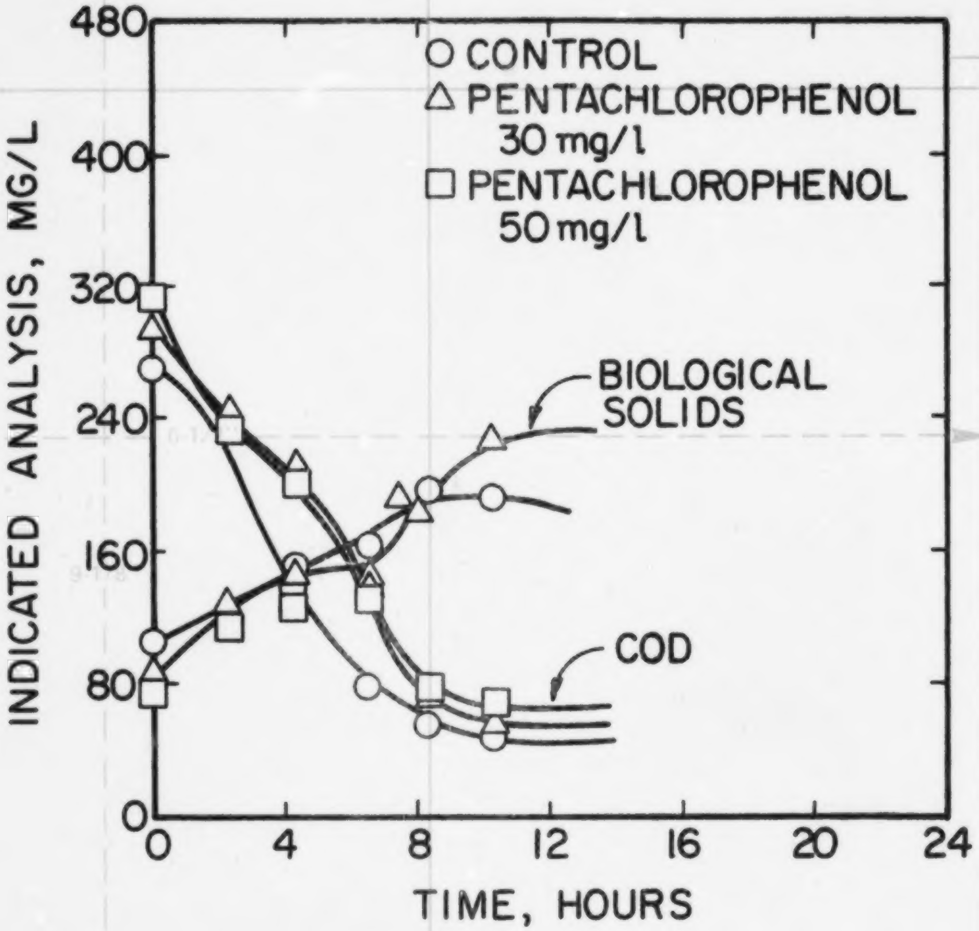

Figure 19. Growth and COD removal of pentachlorophenol unit, dosage=20 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

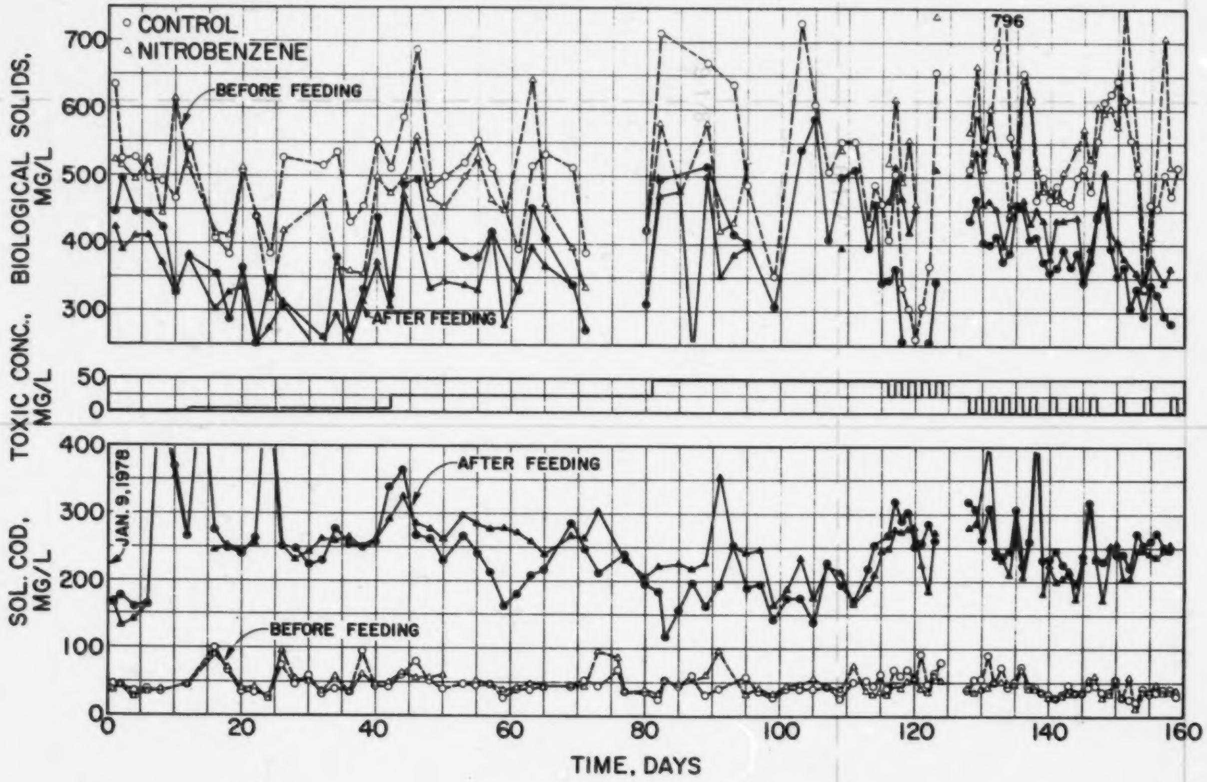

Figure 20. Operational results of batch control and nitrobenzene units.

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

shown in Table 7 indicates that the control unit, on an average, produced slightly lower residual soluble COD than the test unit. Nitrobenzene was stripped slowly under the conditions of the current experimentations, as can be seen in Figure 21.

Comparative rate studies made on the day that nitrobenzene concentration was increased from 25 to 50 mg/l (Figure 22) indicate that the nitrobenzene had little or no effect on the residual COD. Oxygen uptake was determined during this particular study and it is seen that there was a slightly higher accumulated oxygen uptake in the control unit than in the test unit. Only trace concentrations of nitrobenzene were found in the effluent or the mixed liquor.

2-Chlorophenol

The addition of 2-chlorophenol to a unit receiving municipal sewage supplemented with glucose caused a somewhat higher residual soluble COD as compared to the control unit (see Figure 23). It is seen in Table 7 that the average residual COD in the unit receiving 2-chlorophenol dosage was considerably higher than the control, except during the final period when dosage was cyclic.

2-Chlorophenol was only slightly strippable under the conditions of these experimentations as can be seen from Figure 24. A comparison of the performance of the control unit and the system dosed with 2-chlorophenol made on the first day the chlorophenol dosage was changed from 25 to 50 mg/l is shown in Figure 25. It can be seen that the soluble residual COD in the control was significantly lower during the early hours of the experimentation, i.e., 1 - 8 hours. A similar experiment which was run when the dosage was changed from 5 to 25 mg/l of 2-chlorophenol provided similar results. However, when the dosage was changed from 0 to 5 mg/l of chlorophenol, there was essentially no difference in the rates of COD removal in dosed and undosed systems. At the 5 and 25 mg/l dosages there appeared to be some depression in the biological solids concentration in the test unit; however, in the experiment shown here, when the dosage was changed from 25 to 50 mg/l of 2-chlorophenol, there was little or no difference in the biological solids concentration.

Very small amounts of 2-chlorophenol were found in the effluent at any of the three dosage levels. However, a sample taken on June 16, 1978, when the dosage was returned to 25 mg/l in the feed after a 48-hour period of no dosage, indicated approximately 7 mg/l in the mixed liquor solids (0.07 mg/l in the effluent). This suggests that acclimation may be quickly lost even though the compound is taken up by the sludge. The budget of the project permitted only infrequent analyses for specific compounds and the data on the fate of the compound are insufficient to warrant firm conclusions in this regard.

Anthracene

The comparative results for a control system and a unit dosed with

EPA-287 (Cin.)
(4-76)

TABLE 7. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH NITROBENZENE AND 2-CHLOROPHENOL

Date	Parameter	CONTROL				NITROBENZENE				2-CHLOROPHENOL				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1-10-78 to 1-22-78	N	6	7	7	7	6	7	7	7	6	7	7	7	No toxic compound added.
	X	41.3	270.1	527.4	424.0	38.5	255.0	520.0	388.6	45.0	273.3	485.7	400.6	
	σ	5.8	158.9	54.8	54.6	6.7	155.8	51.1	32.6	5.7	152.6	55.7	67.0	
	C.V.%	14.0	58.8	10.4	12.9	17.4	61.1	9.8	8.4	12.7	55.8	11.5	16.7	
	Range	35-48	161-586	468-636	328-496	28-47	134-559	444-616	328-424	39-52	151-579	376-544	292-488	
1-23-78 to 2-20-78	N	14	15	12	12	14	14	12	12	14	15	12	13	5 mg/l toxic compound added.
	X	52.2	292.1	471.3	324.5	54.3	272.9	420.3	301.5	60.3	299.5	388.0	274.0	
	σ	23.5	100.2	61.0	59.0	20.5	66.0	61.5	36.3	29.7	111.1	77.1	43.3	
	C.V.%	45.0	34.3	12.9	18.2	37.8	24.2	14.6	12.0	49.2	37.1	19.9	15.8	
	Range	28-100	224-550	384-552	230-440	24-96	233-497	320-512	252-336	30-131	206-584	280-496	192-324	
2-21-78 to 3-31-78	N	18	17	14	14	17	17	14	14	18	17	18	16	25 mg/l toxic compound added.
	X	45.8	230.9	522.9	398.5	52.0	268.3	497.0	364.5	74.8	273.5	480.9	360.2	
	σ	13.6	40.2	94.5	69.6	17.1	30.3	81.9	62.3	41.2	32.9	62.1	62.5	
	C.V.%	29.7	17.4	18.1	17.5	32.9	11.3	16.5	17.1	55.1	12.0	12.9	17.4	
	Range	24-81	162-314	388-712	273-496	32-96	207-326	336-644	276-472	35-175	209-350	348-596	256-492	
4-1-78 to 5-2-78	N	17	17	11	11	16	16	7	7	16	17	4	4	50 mg/l toxic compound added.
	X	42.4	186.6	546.5	458.5	48.3	221.2	524.6	394.6	50.2	230.5	520.0	454.0	
	σ	10.0	38.0	109.0	80.1	17.4	45.5	95.0	93.6	14.2	34.1	109.6	88.2	
	C.V.%	23.6	20.4	19.9	17.5	36.0	20.6	18.1	23.8	28.3	14.8	21.1	19.4	
	Range	26-60	117-255	352-668	308-584	32-97	164-356	420-696	218-500	25-76	153-287	364-604	348-548	
5-4-78 to 6-16-78	N	42	39	41	40	42	39	33	33	42	38	38	36	Cyclic changes.
	X	47.2	262.3	511.3	358.2	41.6	248.1	552.9	432.1	44.0	237.6	549.2	437.2	
	σ	17.0	39.8	113.6	68.8	11.2	54.3	86.1	52.4	11.4	38.6	88.1	56.7	
	C.V.%	36.0	15.2	22.2	19.2	26.9	21.9	15.6	12.1	25.9	16.2	16.0	13.0	
	Range	20-92	198-412	260-796	184-468	13-69	173-452	412-756	332-536	19-81	177-321	328-880	328-632	

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

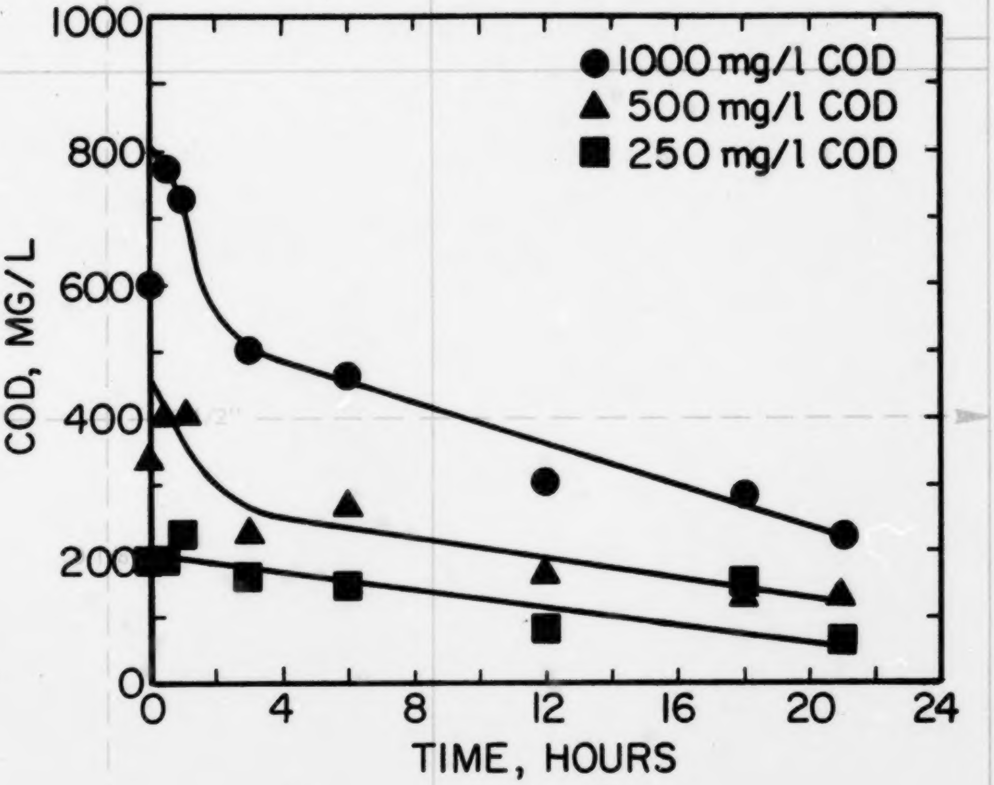

Figure 21. Stripping of nitrobenzene in batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

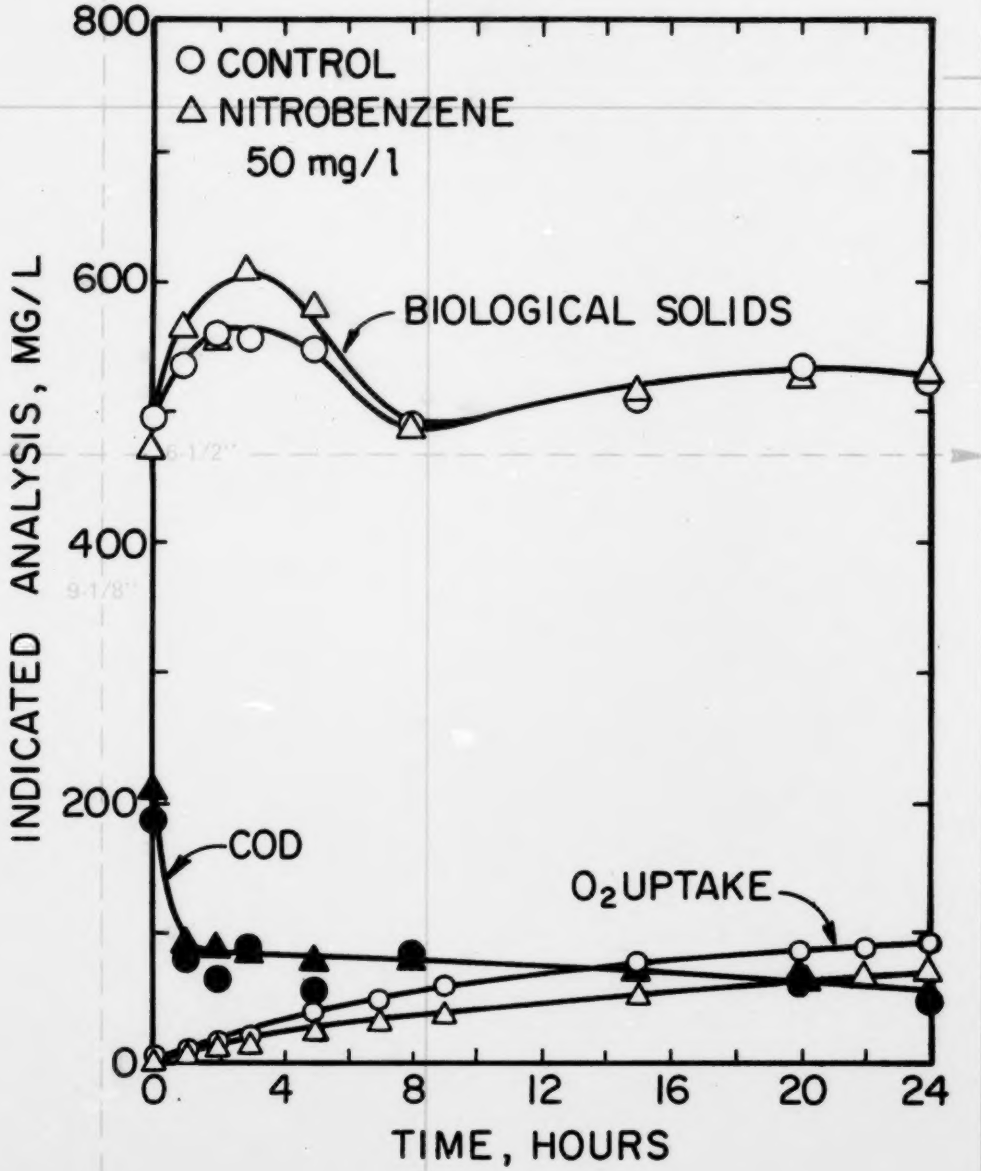

Figure 22. Growth and COD removal of batch nitrobenzene unit, dosage=50 mg/l

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

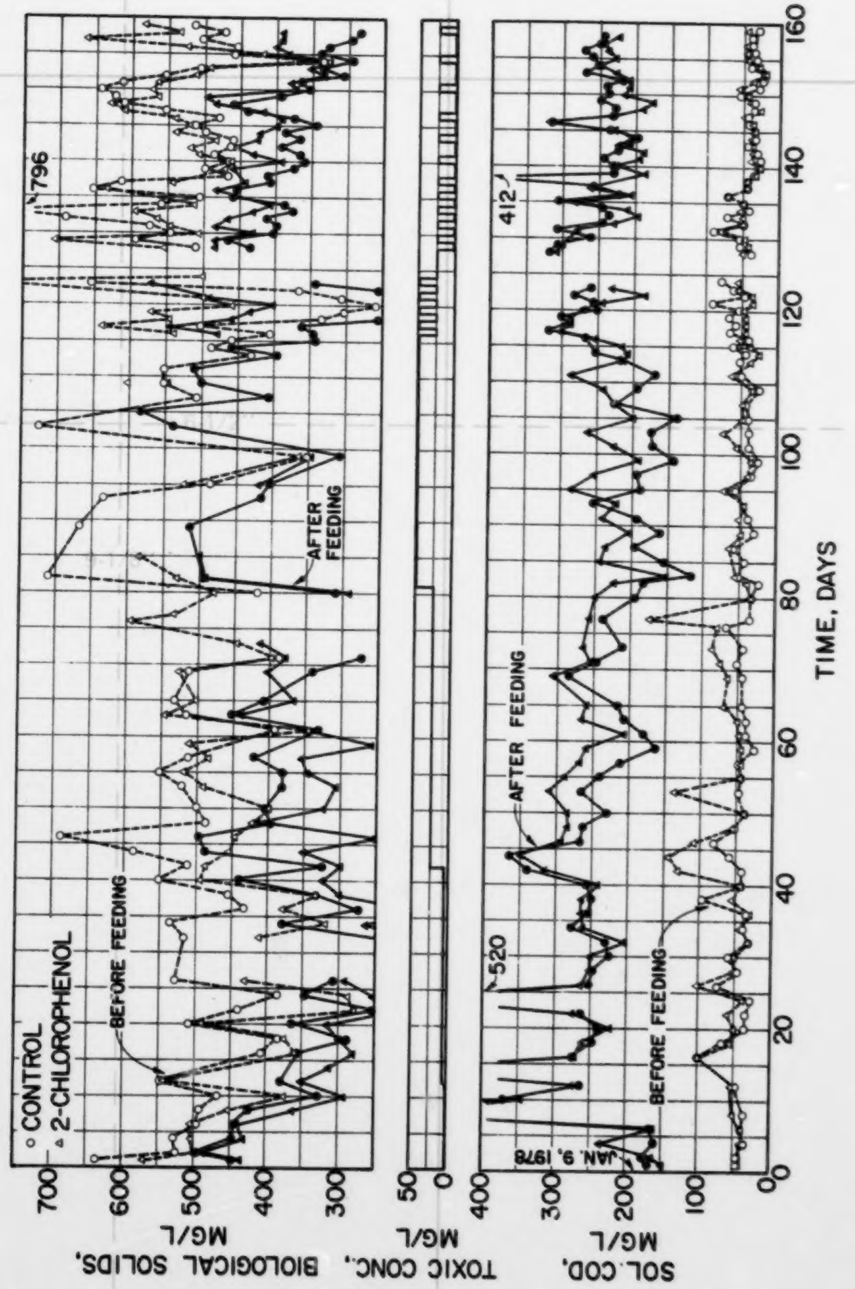

Figure 23. Operational results of batch control and 2-chlorophenol units.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

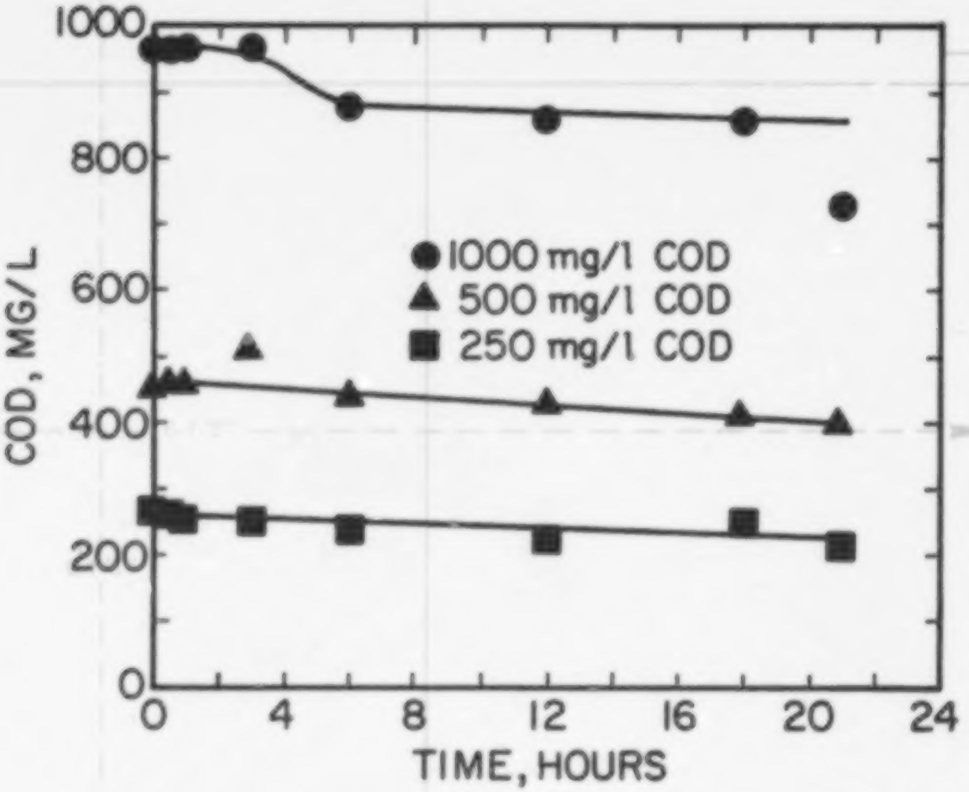

Figure 24. Stripping of 2-chlorophenol in the batch growth reactor.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

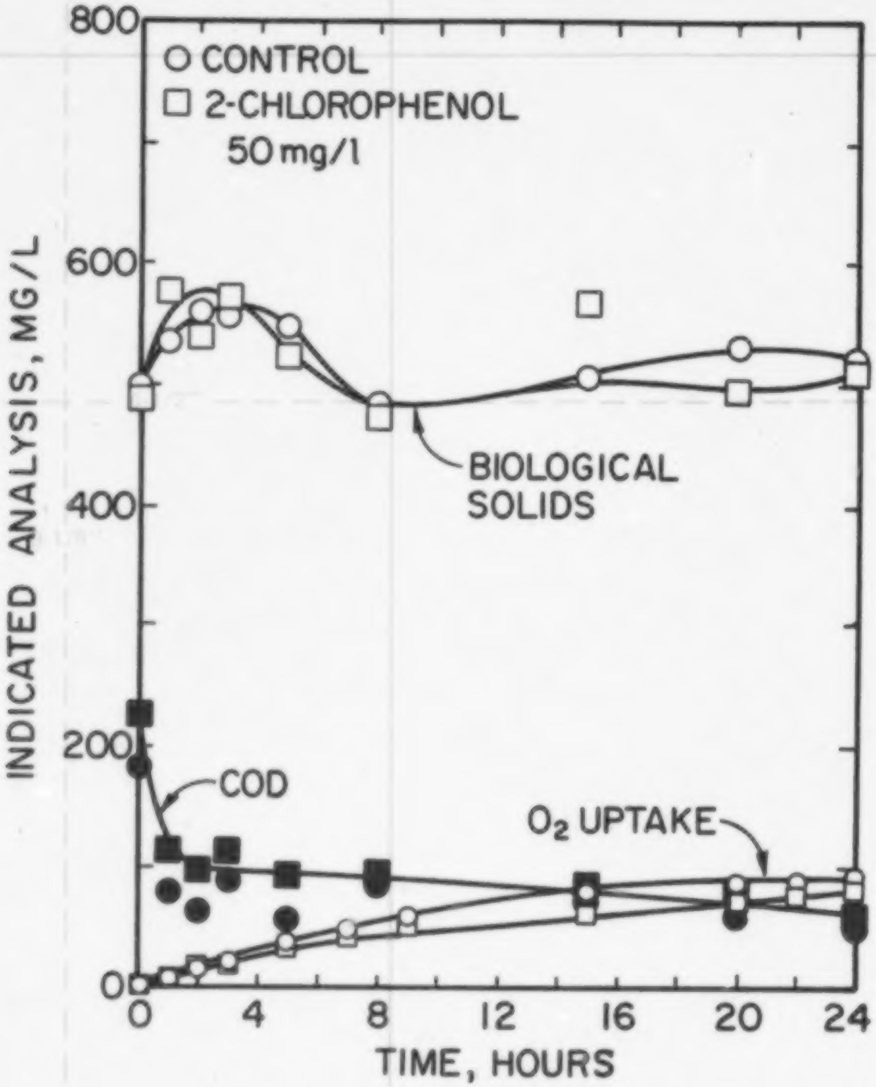

Figure 25. Growth and COD removal of 2-chlorophenol unit, dosage=50 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-76)

varying concentrations of anthracene are shown in Figure 26. At the beginning of the study period there were fluctations in the concentration of COD in the municipal sewage. Also an abnormally high feed COD was manifested on the 129th day. The high soluble COD before feeding on the 74th day corresponded with the occurrence of a large amount of foaming in the unit. The addition of 5 mg/l of anthracene did not appear to affect the behavior of the unit adversely, except for a period between the 25th and 30th days when the residual COD in the anthracene unit was significantly higher than in the control. This result did not greatly affect the mean COD values during this period as can be seen in Table 8. However, it did cause large increases in the standard deviation and coefficient of variation. When the dosage was increased to 25 mg/l, there was little difference in the soluble COD in the control and anthracene units. However, the unit receiving the toxic compound exhibited a somewhat higher biological solids concentration. Increasing the dosage to 50 mg/l did not seriously affect the effluent quality with respect to soluble COD. Fluctuating the loading between 25 and 50 mg/l from the 113th to the 123rd days did not cause any difference in the soluble COD in the control unit and test units. Cycling the loading from 0 to 25 mg/l did not appear to cause any significant differences in the soluble COD. During this peiod there was a considerable drop-off in the biological solids concentration in the control and the anthracene units. Increasing the time of zero concentration, beginning on the 137th day, did not lead to any change in the behavior. That is, the control unit and the anthracene test unit exhibited essentially the same residual COD concentrations. Analyses for anthracene made on mixed liquor and soluble COD indicated that anthracene was removed by the activated sludge.

Figure 27 shows that under the conditions of these experimentations, anthracene was not strippable. Figure 28 shows the results on the first day that the test unit was dosed with 5 mg/l of anthracene. It can be seen that this dosage rate did not affect the system. Experiments performed at higher dosage levels also showed essentially no effect. Analyses for anthracene in the supernatant indicated very low values at all loading levels investigated. Since considerably higher concentrations were found in the mixed liquor (but no indication of build-up in the sludge) it seems safe to conclude that the compound was metabolized by the sludge.

o-Nitrophenol (2-Nitrophenol)

Figure 29 shows that addition of 5 mg/l of o-nitrophenol had only slight effects on the behavior of the system. Statistical analyses shown in Table 8 for this period indicate a slightly higher mean soluble COD and higher coefficient of variation in the unit dosed with o-nitrophenol than in the control system. It is interesting to note that at this dosage level the test compound imparted a visible color to the reaction liquor; the reaction liquor turned slightly yellow. The color persisted until the second day of feeding. However, there was a slight reduction in its intensity by this time. This provided some indication that the o-nitrophenol was partially removed or partially converted to some other colorless compound. This condition prevailed for 8 days. From the 8th day on, even though there was a slight yellow color immediately after feeding, the color had disappeared

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

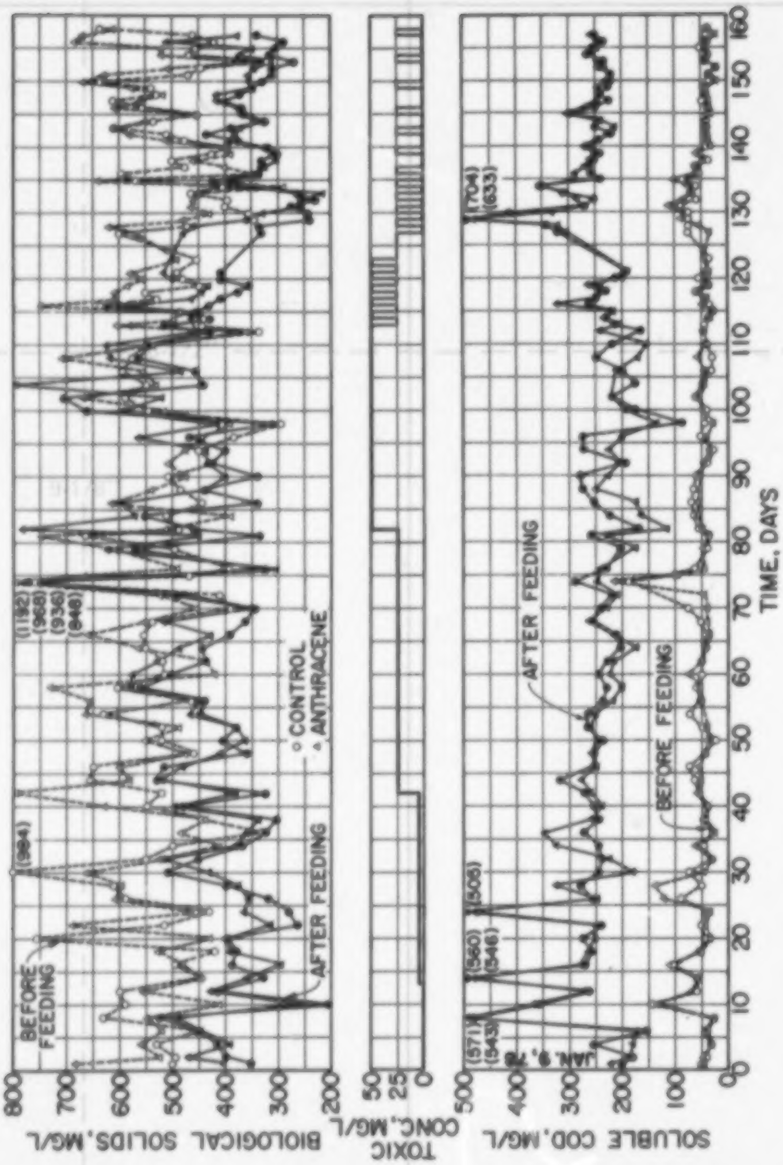

Figure 26. Operational results of batch control and anthracene units.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 8. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH ANTHRACENE AND 2-NITROPHENOL

Date	Parameter	CONTROL				ANTHRACENE				2-NITROPHENOL				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1-10-78 to 1-22-78	N	6	7	7	7	6	7	7	7	6	7	7	7	No toxic compound added.
	X	41.5	275.3	544.0	394.3	42.7	282.3	543.4	413.7	42.8	278.9	556.6	428.6	
	σ	12.4	131.7	65.0	98.9	15.0	145.0	80.0	76.5	18.3	149.2	94.3	58.5	
	C.V.%	30.0	47.8	12.0	25.1	35.1	51.4	14.7	18.5	42.9	53.5	16.9	13.6	
	Range	26-60	154-543	456-632	204-524	26-68	173-571	412-684	260-472	24-76	169-389	448-684	320-504	
1-23-78 to 2-20-78	N	15	15	14	14	15	15	14	14	15	15	14	14	5 mg/l toxic compound added.
	X	54.5	292.6	511.4	358.0	60.1	300.8	527.4	384.3	59.0	293.4	582.9	399.4	
	σ	20.8	93.4	102.0	62.1	35.0	100.8	92.3	61.8	25.0	101.4	86.8	93.5	
	C.V.%	38.2	31.9	19.9	17.4	58.2	33.5	17.5	16.1	42.4	34.6	14.9	23.4	
	Range	30-104	238-560	332-756	268-508	26-138	180-546	412-688	296-516	30-124	214-576	456-696	284-604	
2-2-1-78 to 3-31-78	N	17	17	16	16	17	19	15	15	17	17	14	14	25 mg/l toxic compound added.
	X	52.5	243.9	540.0	420.5	49.1	231.0	583.2	444.3	47.0	268.6	542.9	422.6	
	σ	14.3	27.2	85.6	73.8	15.2	28.8	91.8	72.2	9.3	27.2	96.2	57.8	
	C.V.%	27.2	11.1	15.9	17.5	31.0	12.5	15.7	16.2	19.8	10.2	17.7	13.7	
	Range	36-76	205-318	392-664	324-560	35-95	173-278	420-748	304-580	31-64	220-326	400-704	320-528	
4-1-78 to 5-2-78	N	16	15	9	9	15	16	9	9	16	17	13	13	50 mg/l toxic compound added.
	X	47.5	216.3	504.4	442.7	47.5	194.0	572.4	500.4	47.1	244.7	577.2	446.8	
	σ	12.8	41.2	45.0	77.8	10.8	38.1	82.5	80.7	15.5	44.5	87.7	68.8	
	C.V.%	26.8	19.1	8.9	17.6	22.7	19.6	14.4	16.1	32.9	18.2	15.2	15.4	
	Range	28-69	167-279	340-544	340-564	28-73	117-251	476-708	400-616	26-76	154-348	284-784	308-536	
5-3-78 to 6-16-78	N	41	38	40	39	40	37	38	37	40	37	32	31	Cyclic changes.
	X	48.1	255.7	489.6	343.1	47.5	261.2	536.6	385.3	40.5	256.6	552.4	395.1	
	σ	16.6	43.5	81.8	56.2	21.5	37.3	96.2	80.3	11.3	37.2	101.4	53.8	
	C.V.%	34.6	17.0	16.7	16.4	45.2	14.3	17.9	20.8	27.8	14.5	18.4	13.6	
	Range	21-89	193-412	228-452	228-452	21-112	189-352	352-748	216-592	17-77	178-342	348-768	284-512	

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

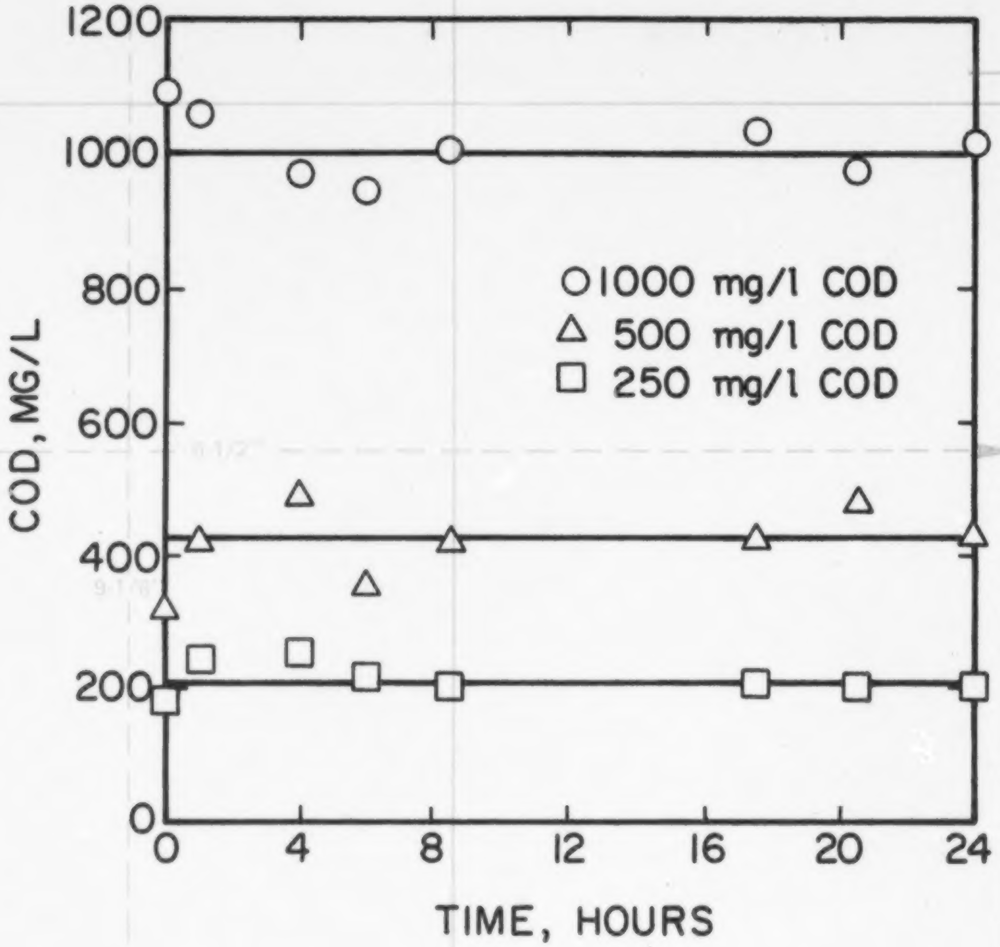

Figure 27. Stripping of anthracene in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

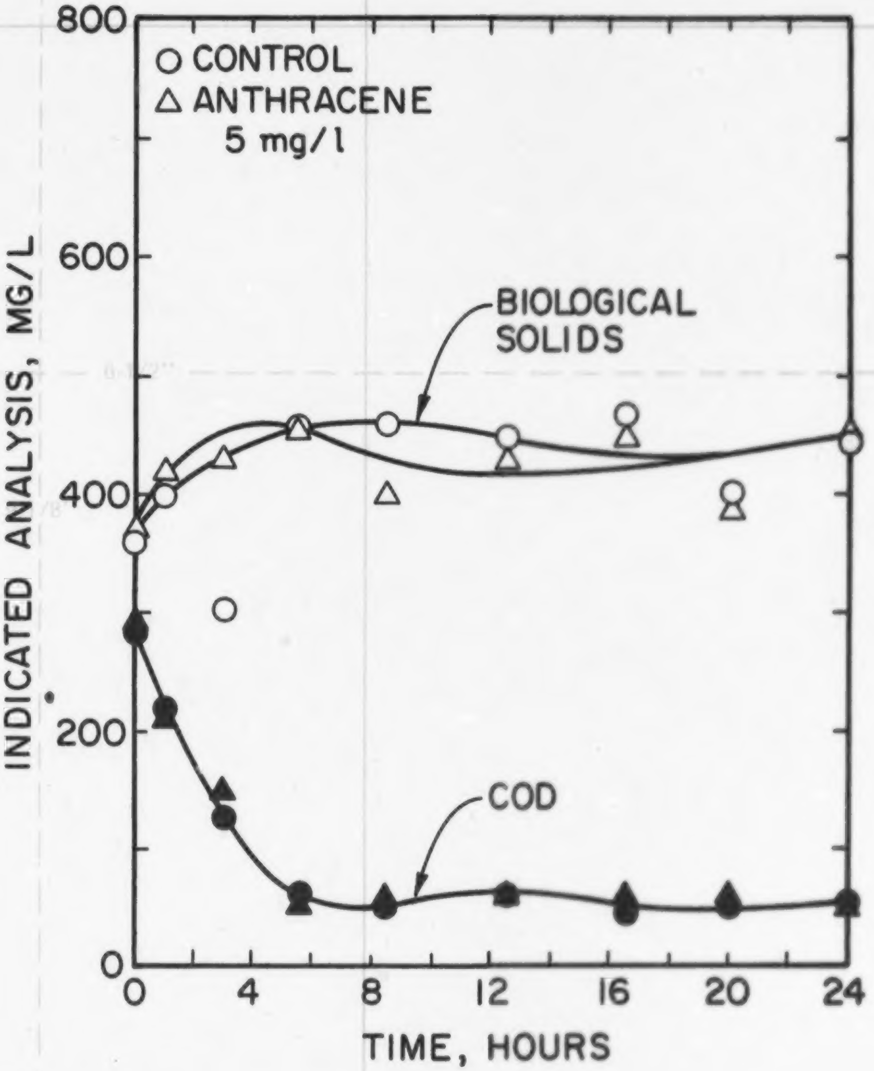

Figure 28. Growth and COD removal of batch anthracene unit, dosage=5 mg/1.

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

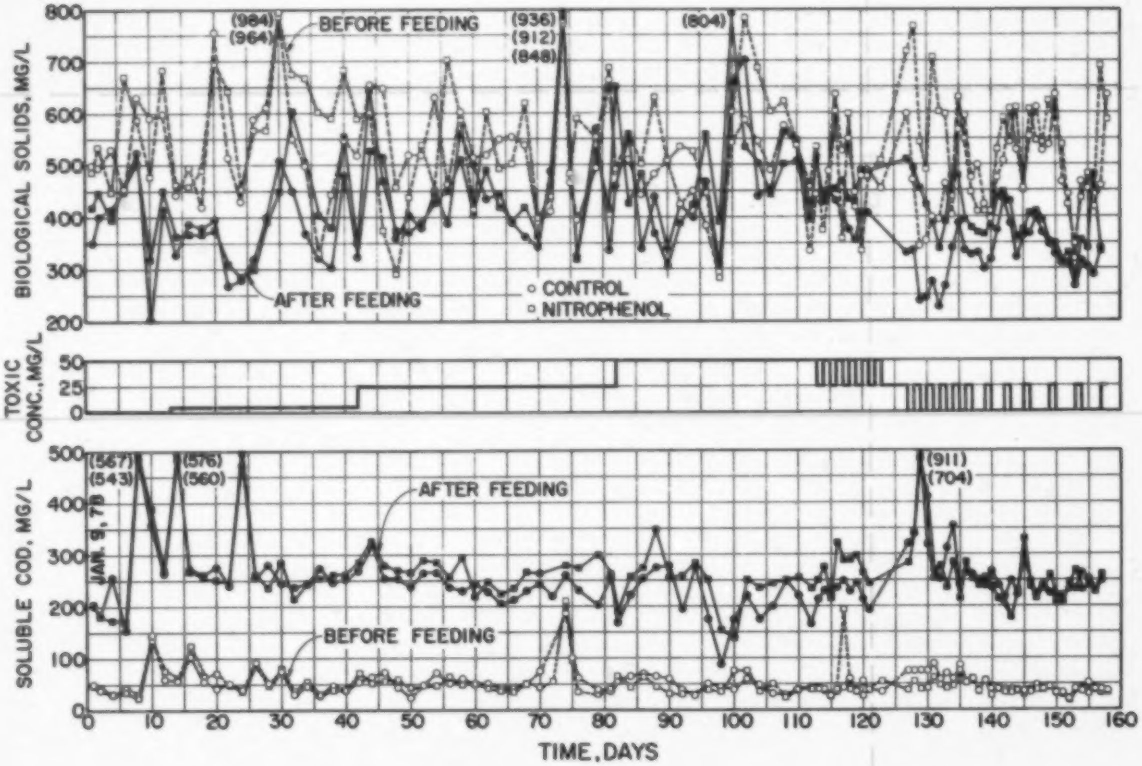

Figure 29. Operational results of batch control and 2-nitrophenol.

before the next feeding. When the dosage was increased to 25 mg/l on the 42nd day, the yellow color again increased after feeding. In response to this dosing level, there was a decrease in biomass concentration; however, the biomass level recovered after the first four days of this dosing level. The color due to the presence of o-nitrophenol was removed during the first day of dosage at this level. When the dosage was increased to 50 mg/l, the yellow color of o-nitrophenol was not removed on the first day; however, after three days of such feeding, o-nitrophenol was removed during the daily feeding period as evidenced by the absence of color when compared to the control.

During the period of feeding 50 mg/l, the suspended solids concentration in the unit receiving o-nitrophenol became higher than in the control. The fact that the residual COD at the end of the feeding period was essentially the same as in the control whereas the higher COD due to the feeding of o-nitrophenol was evident in the sample taken immediately after feeding, coupled with the fact that the biological solids concentration was somewhat higher during this feeding period, can be taken as rather good evidence that the compound was assimilated by the sludge. When the loading was fluctuated between 25 and 50 mg/l between the 113th and 123rd days, the biomass concentration in the o-nitrophenol unit fluctuated considerably. When the cyclic loading was 0→25→0 mg/l, the suspended solids concentration in the o-nitrophenol unit remained somewhat higher than in the control.

The settling characteristics of the o-nitrophenol unit compared very favorably throughout the experimental period with those exhibited by the control. A few analyses were made for the presence of o-nitrophenol in the effluent and in the mixed liquor. Only trace values were ever found, thus indicating that the o-nitrophenol was indeed removed during the aeration period.

Stripping tests run on the unit indicate that the test compound was only slightly strippable and then only at high concentrations (see Figure 30). Under the conditions of these experimentations o-nitrophenol can be considered to be a non-strippable compound.

Figure 31 shows the results when the o-nitriphenol concentration was increased from 0 to 5 mg/l. It is seen that there was no effect on the rate of substrate removal. However, at higher concentrations, for example when the dosage was changed from 25 to 50 mg/l o-nitrophenol, there was some decrease in the rate of COD removal.

Hexachloroethane

From the results shown in Figure 32, it is apparent that dosages of hexachloroethane up to 50 mg/l in the feed had little or no effect on the system. Cycling the loading from 25 to 50 mg/l and from 0 to 25 mg/l also had no effect compared to the performance of the control system. This observation is enforced by the results of the statistical analyses shown in Table 9.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

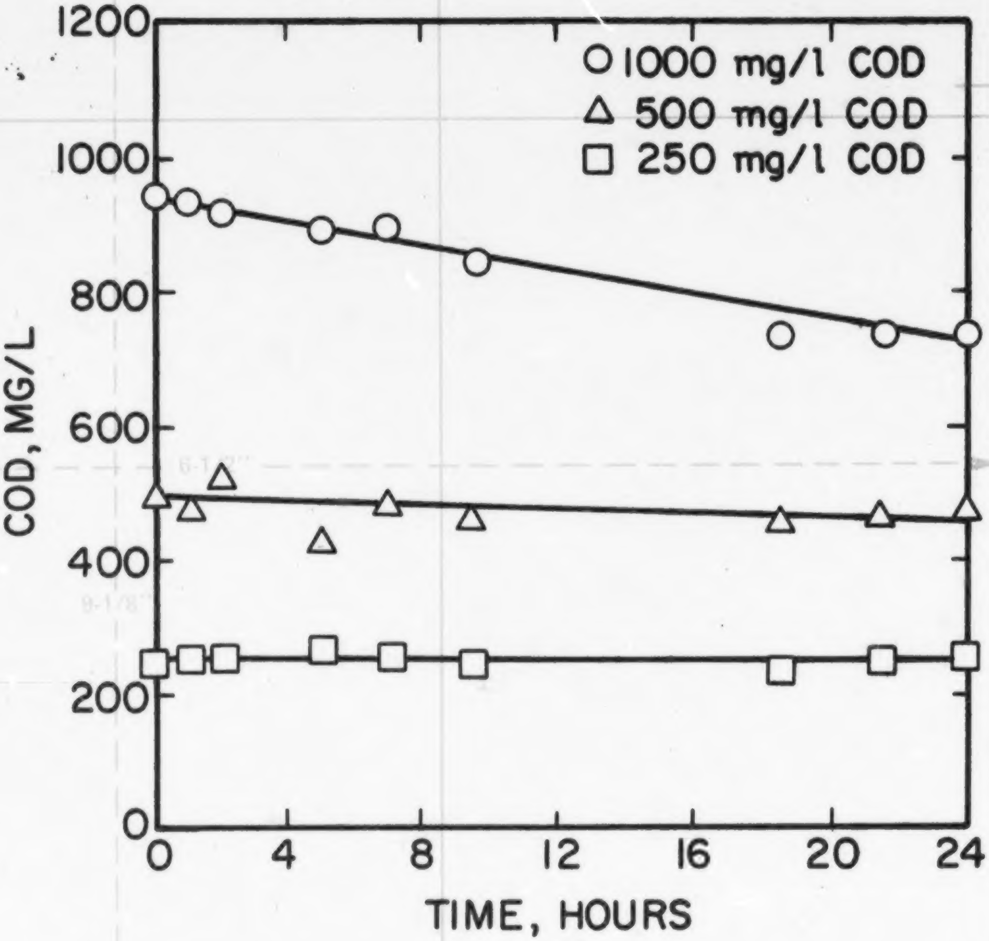

Figure 30. Stripping of 2-nitrophenol in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

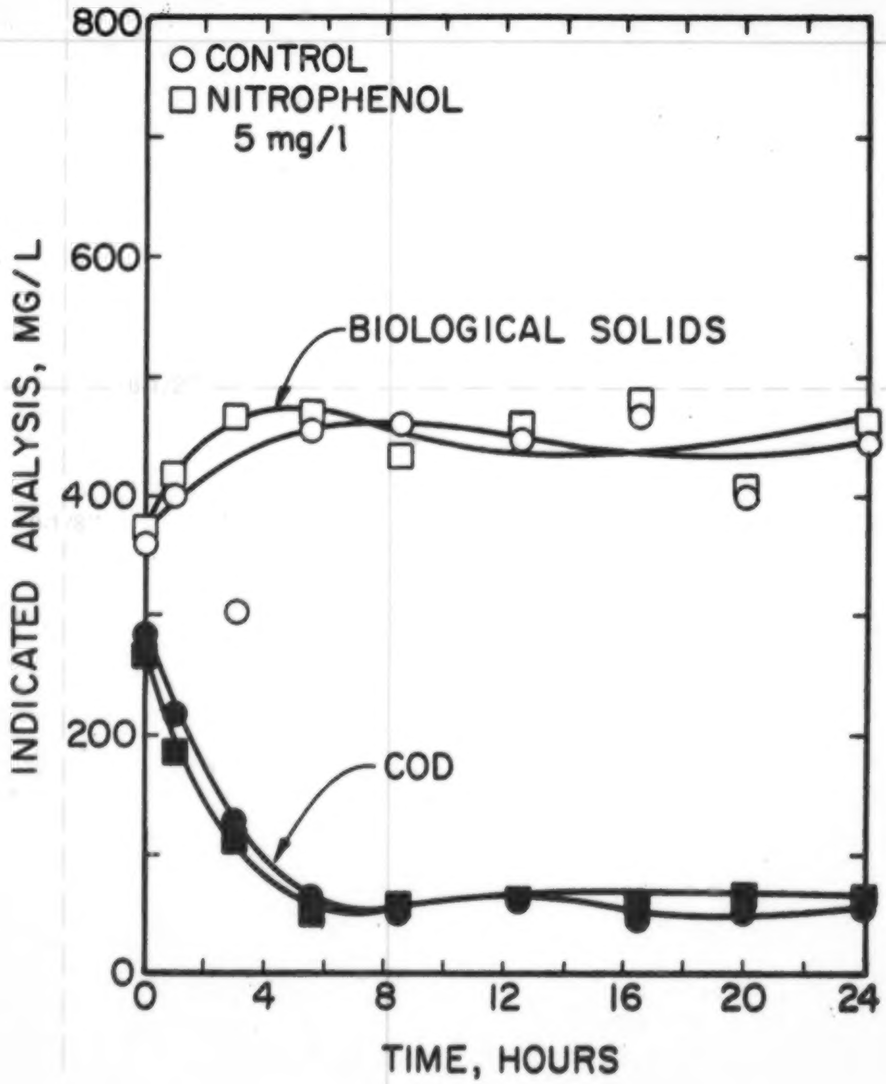

Figure 31. Growth and COD removal of batch 2-nitrophenol unit, dosage=5 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

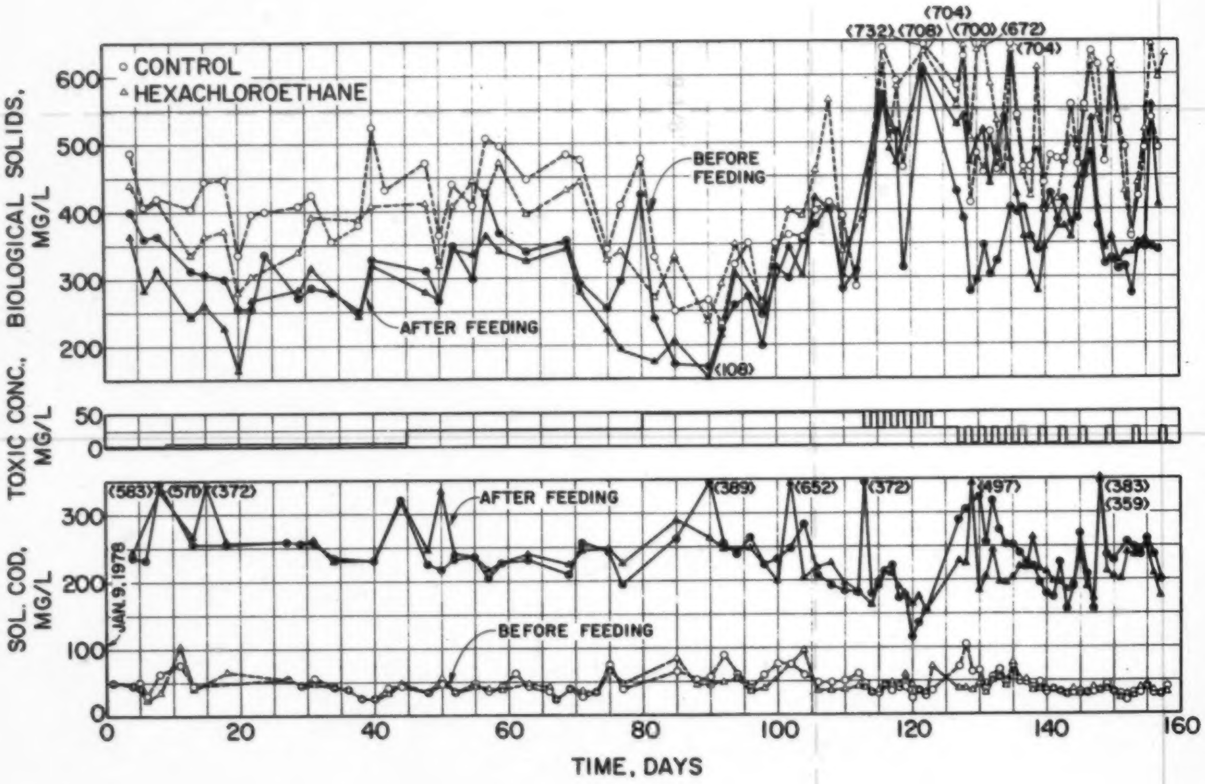

Figure 32. Operational results of batch control and hexachloroethane units.

TABLE 9. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH HEXACHLOROETHANE AND FLUORENE

Date	Parameter	CONTROL				HEXACHLOROETHANE				FLUORENE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1-10-78 to 1-17-78	N	5	3	3	3	5	2	3	3	5	3	3	3	No toxic compound added.
	X	48.2	350.3	438.7	374.7	40.0	407.5	420.0	321.3	39.0	346.3	428.0	313.3	
	σ	11.6	201.5	43.1	22.0	10.7	231.2	18.3	40.3	7.5	198.2	10.6	14.0	
	C.V.%	24.1	57.5	9.8	5.9	26.8	56.7	4.4	12.5	19.2	57.2	2.5	4.5	
	Range	31-63	232-583	408-488	360-400	24-51	244-571	404-440	284-364	31-51	224-575	416-436	300-328	
1-18-78 to 2-23-78	N	11	8	12	11	12	9	9	9	12	9	10	10	5 mg/1 toxic compound added.
	X	45.2	259.2	412.7	289.8	47.9	273.1	353.8	259.1	42.0	260.6	435.6	308.0	
	σ	14.0	27.3	48.5	29.4	21.0	44.7	42.5	47.6	11.4	47.5	37.1	35.3	
	C.V.%	30.9	10.5	11.7	10.1	43.8	16.4	12.0	18.4	27.1	18.2	8.5	11.4	
	Range	26-76	232-321	336-524	252-336	26-104	230-372	280-408	164-320	18-60	217-364	376-496	236-352	
2-24-78 to 3-31-78	N	15	11	12	12	14	11	11	11	15	11	12	12	25 mg/1 toxic compound added.
	X	41.9	225.7	443.7	332.0	42.1	244.3	402.4	298.5	41.7	226.8	416.0	320.7	
	σ	12.9	17.9	52.4	55.0	10.3	31.3	51.4	54.8	13.6	14.0	47.5	53.0	
	C.V.%	30.9	7.9	11.8	16.6	24.5	12.8	12.8	18.4	32.6	6.2	11.4	16.5	
	Range	24-75	195-257	344-508	256-424	24-67	217-334	320-472	196-364	23-68	195-241	292-468	212-412	
4-1-78 to 5-2-78	N	15	14	14	14	13	12	12	11	14	13	11	11	50 mg/1 toxic compound added.
	X	59.4	252.8	326.6	278.0	49.6	262.8	358.0	276.4	44.3	232.4	358.9	294.2	
	σ	13.1	62.3	59.8	73.7	19.2	126.3	92.2	95.5	10.8	38.5	76.2	79.1	
	C.V.%	22.1	24.6	18.3	26.5	38.6	48.1	25.7	34.5	24.4	16.6	21.2	26.9	
	Range	40-89	183-389	232-412	168-408	36-96	183-652	236-564	108-420	28-65	195-328	216-492	156-428	
5-3-78 to 6-16-78	N	42	38	34	34	42	40	35	34	42	40	38	37	Cyclic changes.
	X	41.6	225.0	522.2	379.3	40.3	217.8	544.7	432.4	40.4	221.6	531.7	385.0	
	σ	16.0	53.6	84.5	75.7	11.0	58.9	91.6	88.4	11.6	33.1	104.7	94.8	
	C.V.%	38.5	23.8	16.2	20.0	27.3	27.0	16.8	20.4	28.7	14.9	19.7	24.6	
	Range	21-104	116-359	360-732	276-604	25-77	156-497	368-708	280-612	24-81	153-314	364-824	240-568	

It can be seen from Figure 33 that changing the dosage from 25 to 50 mg/l hexachloroethane in the feed had little or no effect on the performance of the system compared to the control. The calculated COD of hexachloroethane is 0.27 mg oxygen per mg but when enough compound to give 1000 mg/l COD was subjected to the standard COD analyses, only trace concentrations of COD were registered. Thus attempts to run stripping tests were abandoned. Only trace amounts of the compound were registered in the few effluent samples analyzed for hexachloroethane.

Fluorene

The results using fluorene were essentially the same as those for hexachloroethane in that the soluble COD compared favorably with the soluble COD in the control unit (see Figure 34). Statistical analyses shown in Table 9 substantiate this conclusion. Under the conditions of the current investigation, fluorene was not stripped from the system (see Figure 35).

A study of growth and COD removal run concurrently on the control and the unit dosed with fluorene at a feed level of 50 mg/l is shown in Figure 36 and it is seen that the presence of fluorene did not affect the results. Analyses for fluorene in the effluent were done only infrequently but only trace amounts were found. Analyses made on the mixed liquor indicated higher concentrations. The highest value recorded was 15 mg/l but there was no indication that the compound was accumulating in the sludge. More information is needed on the fate of this compound.

Methylene Chloride

It is seen from Figure 37 that addition of methylene chloride at 5, 25 or 50 mg/l in the incoming feed had little or no effect on the soluble COD in the effluent or on biological solids production. Statistical analysis showed that the average soluble COD and biomass production were approximately the same in the control and the test units (Table 10).

Methylene chloride strips from the system extremely rapidly as is seen in Figure 38. COD removal and biomass accumulation studies made periodically during the batch test period indicated that here was little or no effect to be expected from addition of methylene chloride in the range of concentrations examined in this investigation. For example, Figure 39 shows the comparative results on the first day of addition of 5 mg/l methylene chloride in the feed, i.e., on the 8th day of the pilot plant log shown in Figure 37. Similar rate studies made when the dosages were pulsed, indicated little or no effect. In one study, after withholding methylene chloride for two days and then adding 25 mg/l in the feed, there was evidence for some retardation of COD removal rate and sludge accumulation rate. Methylene chloride did not appear to adversely affect the suspended solid concentration in settled effluent and only trace amounts of the compound were detected in the effluent.

Carbon Tetrachloride

The behavior of the system receiving varying dosages of carbon tetra-

EPA-287 (Cin.)
(4-76)

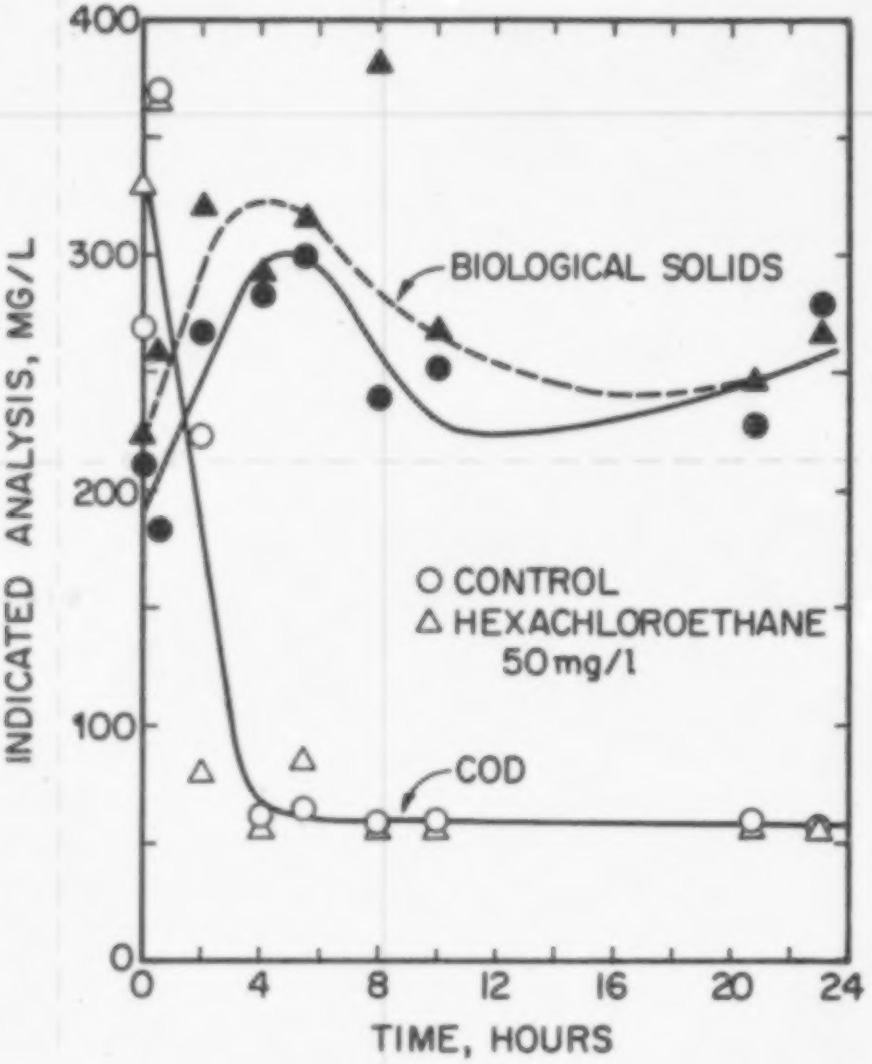

Figure 33. Growth and COD removal of hexachloroethane unit, dosage=50 mg/l.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

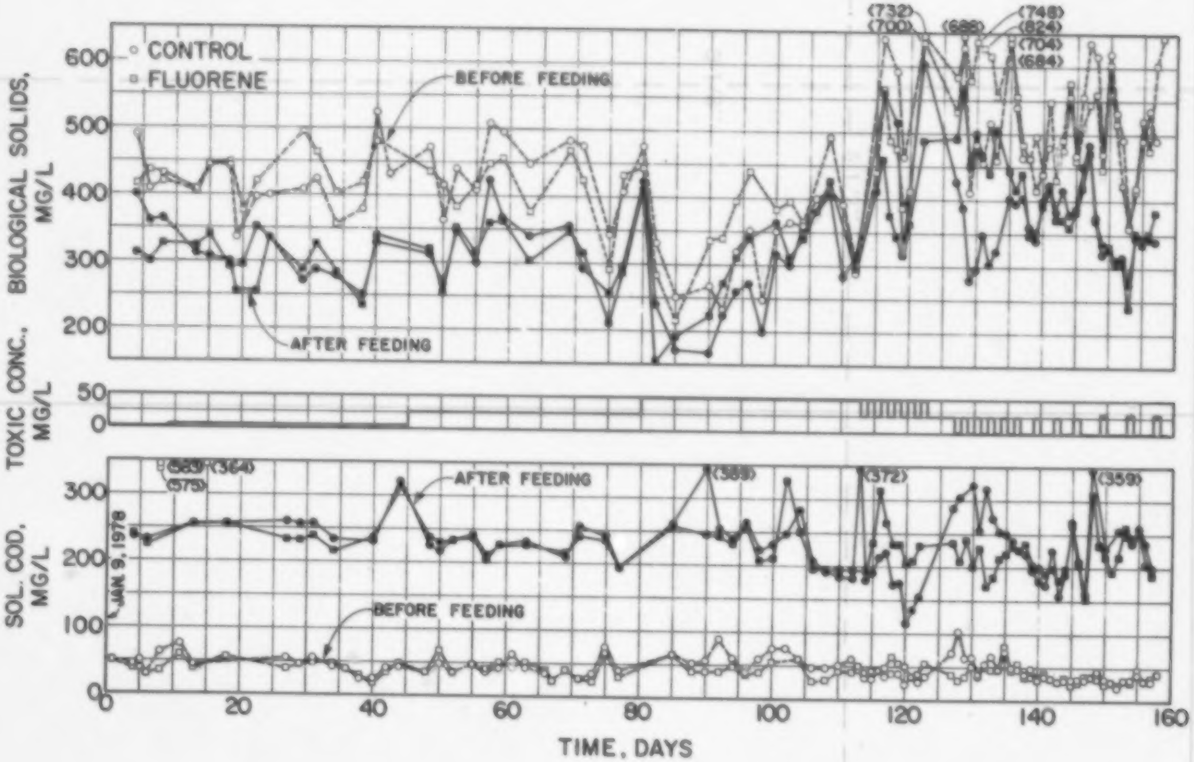

Figure 34. Operational results of batch control and fluorene units.

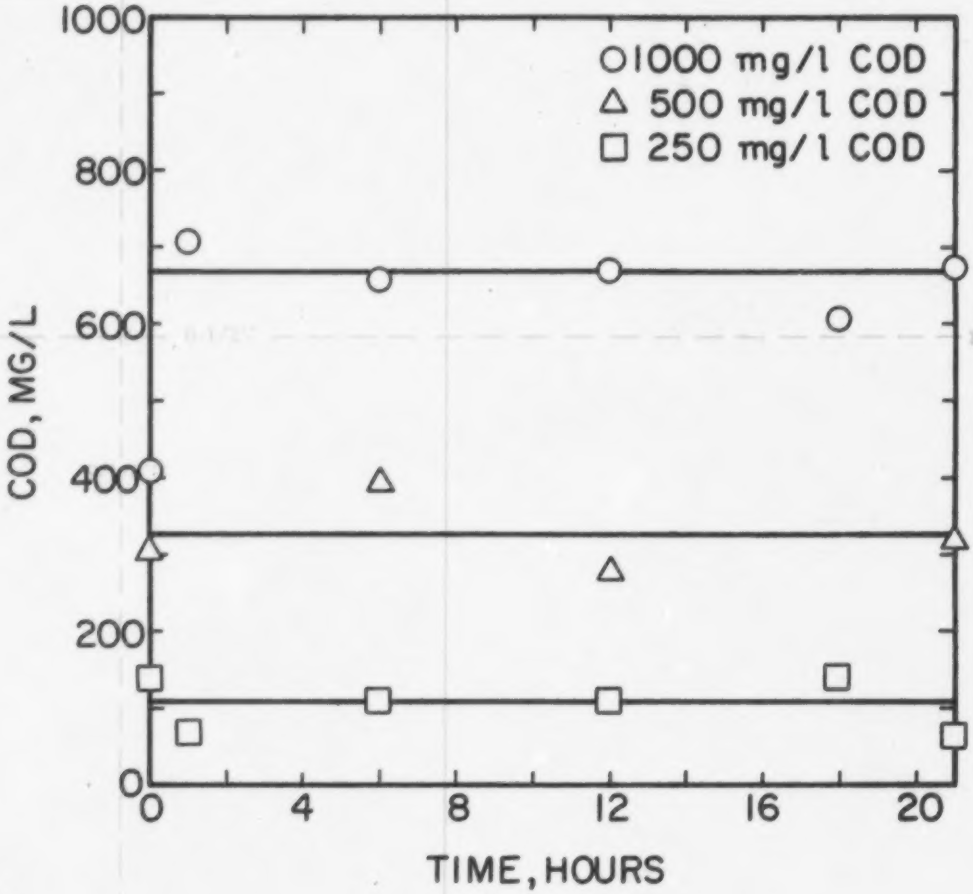

Figure 35. Stripping of fluorene in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

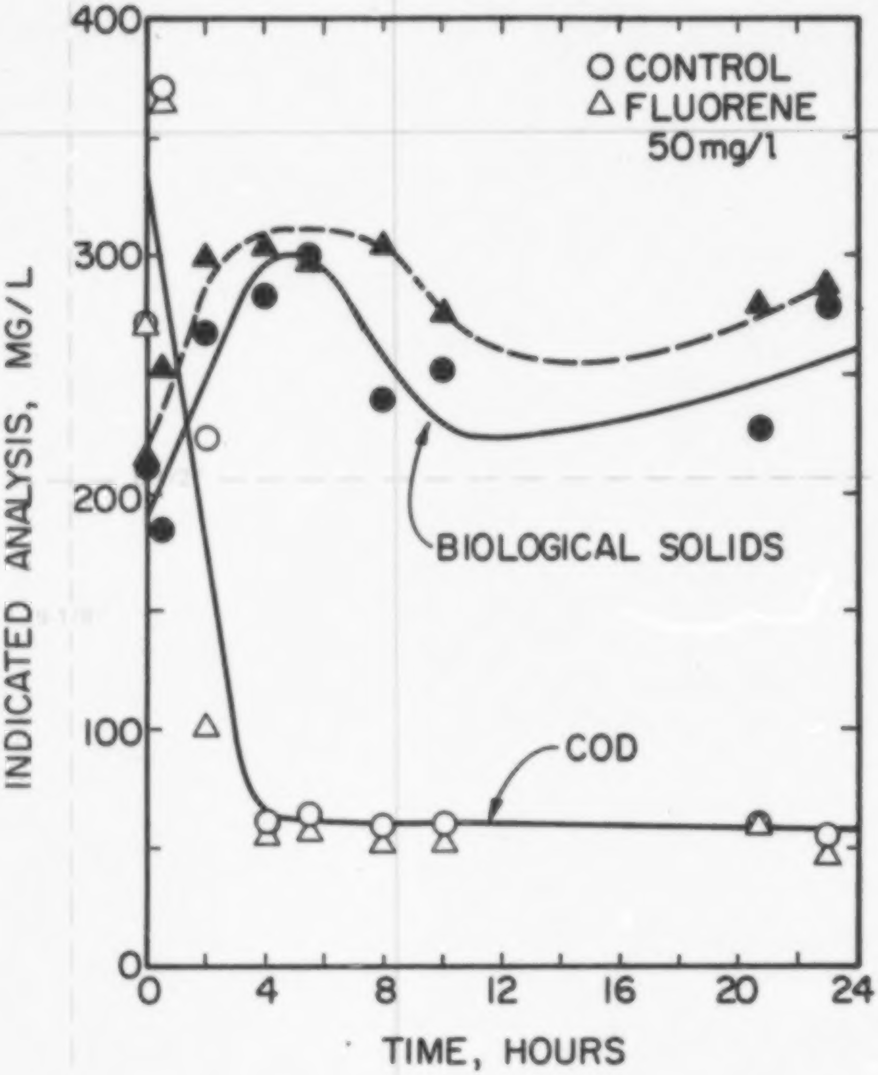

Figure 36. Growth and COD removal of batch fluorene unit, dosage=50 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

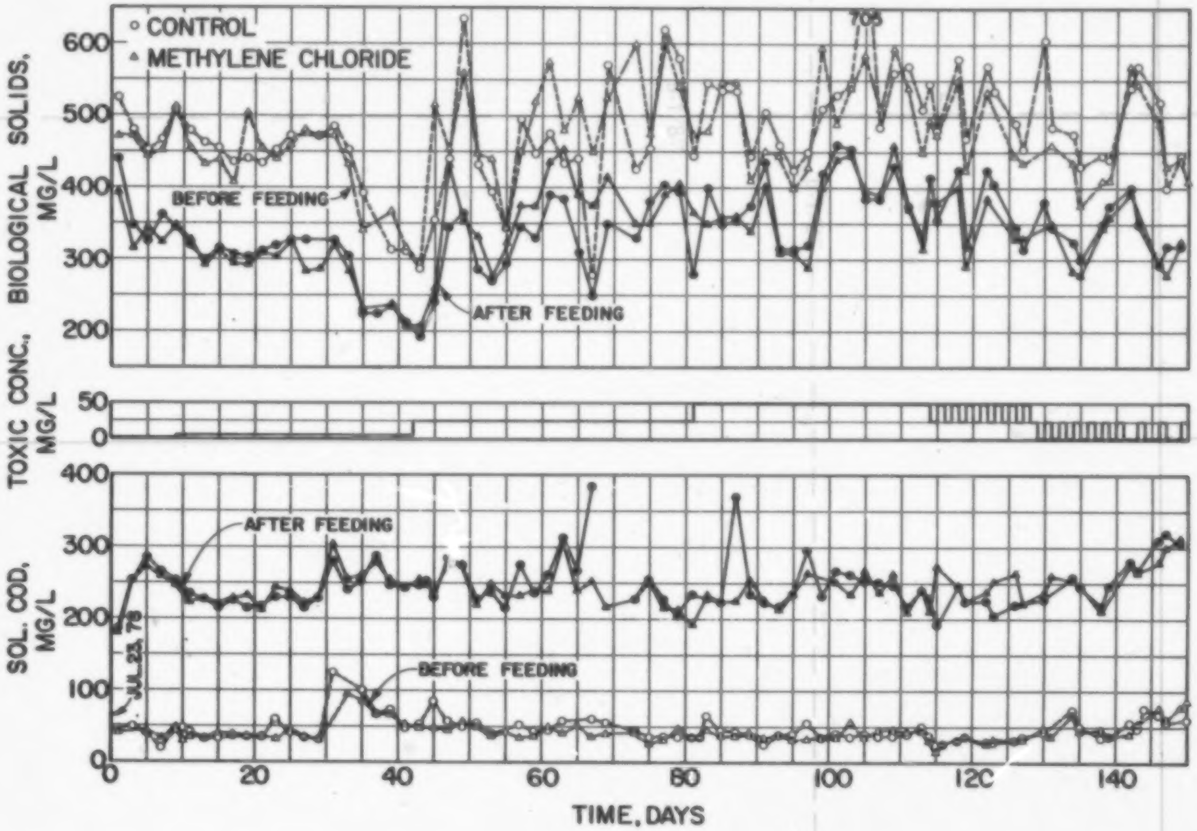

Figure 37. Operational results of batch control and methylene chloride units.

TABLE 10. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH METHYLENE CHLORIDE AND CARBON TETRACHLORIDE

Date	Parameter	CONTROL				METHYLENE CHLORIDE				CARBON TETRACHLORIDE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
7-24-78 to 8-1-78	N	5	5	5	5	4	5	5	5	5	5	5	5	No toxic compound added.
	X	39.6	247.6	486.4	358.8	41.2	242.6	470.4	344.8	36.0	232.6	476.0	367.2	
	σ	11.4	37.3	29.3	46.3	6.7	36.1	26.3	29.6	5.3	33.6	33.1	36.7	
	C.V.%	28.8	15.1	6.0	12.9	16.3	14.9	5.6	8.6	14.7	14.4	7.0	10.0	
	Range	20-49	185-284	452-524	324-440	32-48	180-272	444-512	316-392	28-43	175-260	436-516	344-432	
8-2-78 to 9-3-78	N	16	16	14	15	16	16.	15	15	16	16	16	16	5 mg/l toxic compound.
	X	52.6	238.1	433.0	290.9	47.9	242.5	431.7	287.7	47.3	242.4	443.0	290.5	
	σ	26.7	21.1	55.5	42.9	20.1	24.1	53.0	35.9	16.1	28.3	50.1	37.8	
	C.V.%	50.8	8.9	12.8	14.8	42.1	9.9	12.3	12.5	34.0	11.7	11.3	13.0	
	Range	32-124	215-288	312-484	212-328	32-96	212-304	316-504	208-328	32-92	208-296	336-548	232-328	
9-4-78 to 10-12-78	N	17	19	19	19	19	20	19	19	18	18	18	19	25 mg/l toxic compound added.
	X	49.6	256.2	450.3	323.3	42.5	242.0	488.2	361.3	47.2	252.5	478.3	315.3	
	σ	12.4	41.0	99.2	59.2	7.7	26.2	78.9	62.3	10.3	28.7	89.8	53.0	
	C.V.%	25.0	16.0	22.0	18.3	18.1	10.8	16.2	17.3	21.8	11.4	18.8	16.8	
	Range	36-85	204-385	280-636	192-405	28-52	192-309	296-605	208-455	28-64	212-317	312-660	220-440	
10-13-78 to 11-14-78	N	18	17	17	17	18	16	17	17	17	16	17	17	50 mg/l toxic compound
	X	41.1	249.4	521.5	383.5	39.6	237.6	500.3	371.8	39.0	236.9	489.7	374.4	
	σ	8.8	37.1	64.0	47.9	6.2	18.7	63.3	50.0	6.1	20.7	66.1	50.0	
	C.V.%	21.4	14.9	12.3	12.5	15.7	7.9	12.7	13.4	15.6	8.7	13.5	13.4	
	Range	26-66	217-370	425-705	315-460	32-56	211-268	400-595	290-460	31-52	205-292	375-605	285-460	
11-15-78 to 12-20-78	N	19	17	18	18	21	17	17	16	21	18	16	16	Cyclic changes.
	X	44.3	248.1	496.7	352.8	47.1	257.5	461.2	335.9	49.2	262.1	440.6	322.1	
	σ	16.3	37.2	59.5	40.8	18.9	26.6	57.5	41.4	23.2	30.0	78.8	44.5	
	C.V.%	36.8	15.0	12.0	11.6	40.1	10.3	12.5	12.3	47.2	11.4	17.9	13.8	
	Range	25-76	193-320	400-610	295-425	16-88	213-312	375-570	280-400	21-112	218-320	330-605	258-415	

EPA-287 (Cin.)
(4-76)

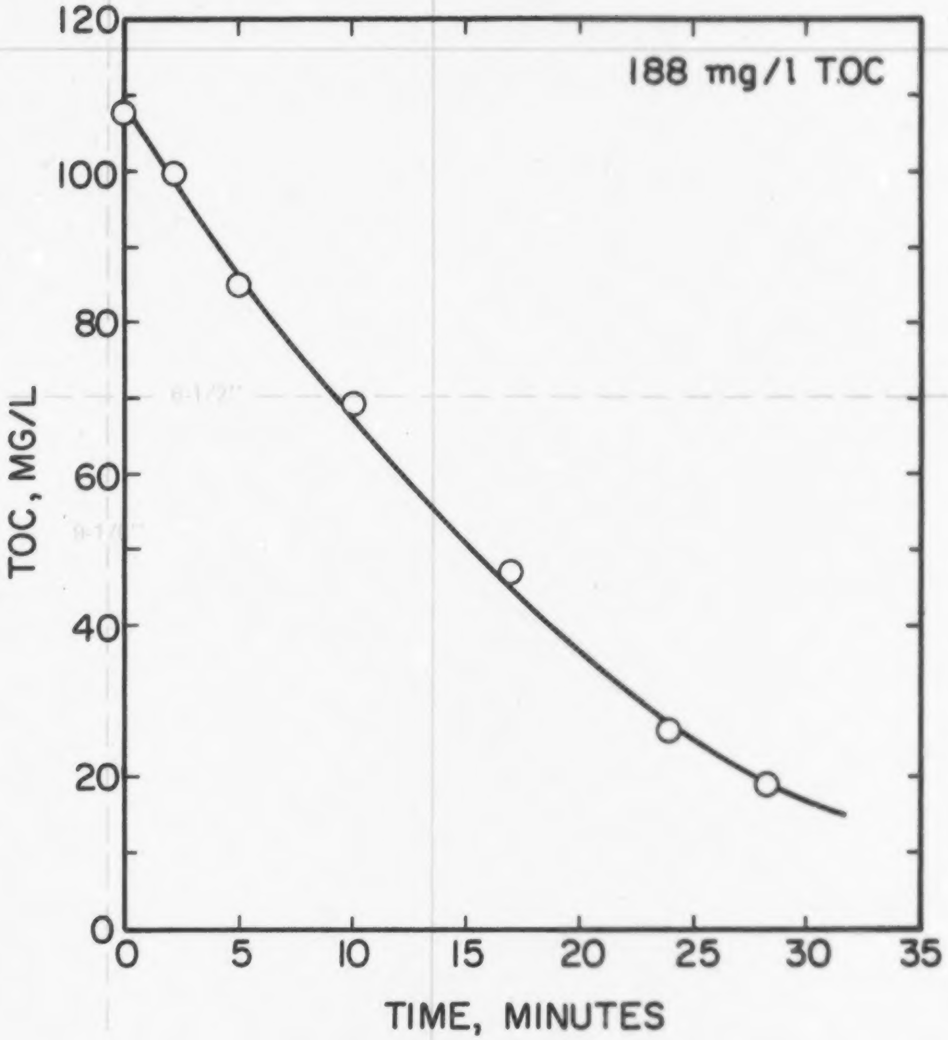

Figure 38. Stripping of methylene chloride in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

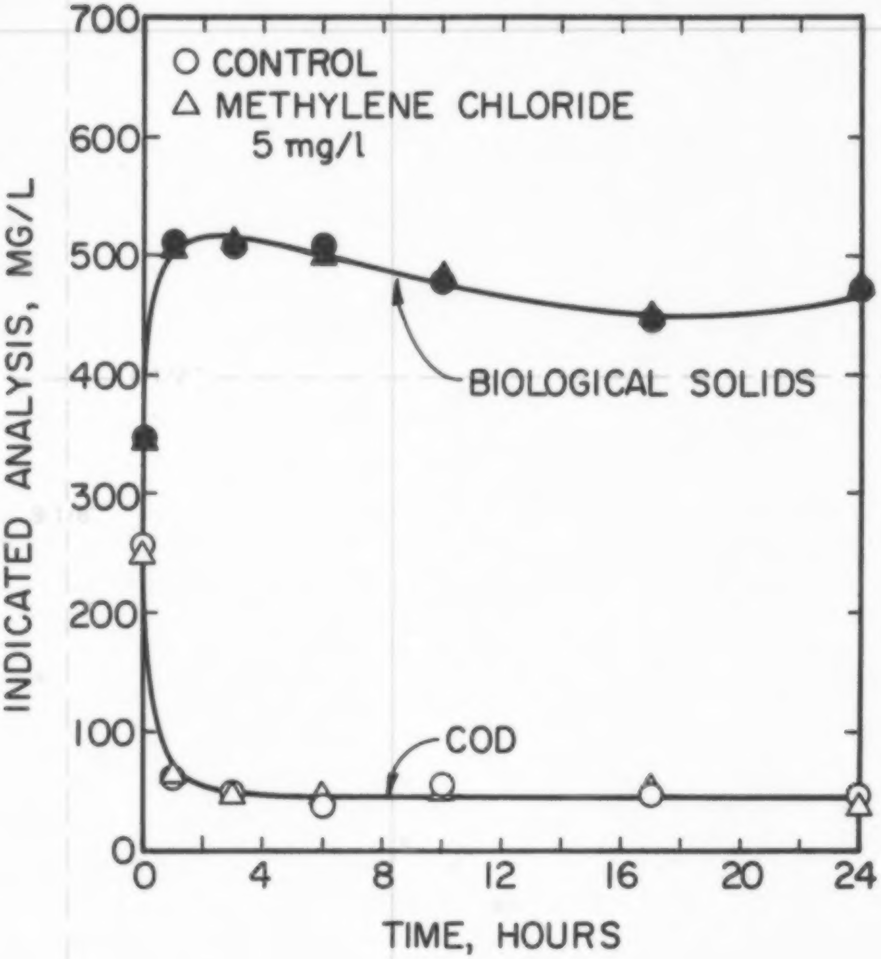

Figure 39. Growth and COD removal of methylene chloride unit, dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

chloride was very much like that of the unit which received methylene chloride. The impression received from viewing the data plot of Figure 40 is reinforced by the statistical analysis shown in Table 10.

Carbon tetrachloride was rapidly stripped from the system under the experimental conditions of these experimentations as shown in Figure 41. For this experiment, TOC was used as the measurement of organic matter rather than COD.

Studies of growth and substrate removal rate made on the first day that the system was dosed with 5 mg/l carbon tetrachloride are shown in Figure 42. It is apparent that the addition of the test compound had no effect on the behavior of the system. Similar studies made when the dosage was changed from 5 to 25 mg/l and from 25 to 50 mg/l, as well as when the dosage was pulsed, indicated little or no effect of carbon tetrachloride. There was some retardation of COD removal and biological solids production during a rate study made after dosing the system with 25 mg/l of the carbon tetrachloride after a resting period of 48 hours in the absence of the test compound. Small amounts (less than 1 mg/l) were sometimes noted in settled supernatant.

Chloroform

Figure 43 shows the results obtained when varying concentrations of chloroform were administered to the batch activated sludge system. It is seen that the results for the unit receiving chloroform were essentially the same as for the control system. The statistical analyses shown in Table 11 indicate little or no difference in soluble COD and biomass concentrations in the chloroform units and the control at all dosage levels.

Stripping tests run at various chloroform concentrations under conditions of air flow similar to those existing in the batch units indicate that chloroform is rapidly lost from the system. Chloroform is only slightly soluble in water and is partially emulsified by the agitation provided by diffused aeration. Sample results of stripping tests are shown in Figure 44.

Studies of COD removal and biomass growth made on the days when the chloroform concentration was changed indicated that the increase in chloroform concentration had little or no effect on the metabolic behavior of the system. Figure 45 shows the comparative results when the chloroform concentration was changed from 0 to 5 mg/l in the feed.

Settling tests made at various times during the experimental period indicated that the biological solids concentration in the supernatant after one hour of quiescent settling was essentially the same in the dosed unit and in the control unit. The results of several analyses for chloroform in the settled effluent indicated that small quantities (< 0.2 mg/l) remained after the 23-hour aeration period.

Trichloroethylene

It can be seen from Figure 46 that the performance of the unit which

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

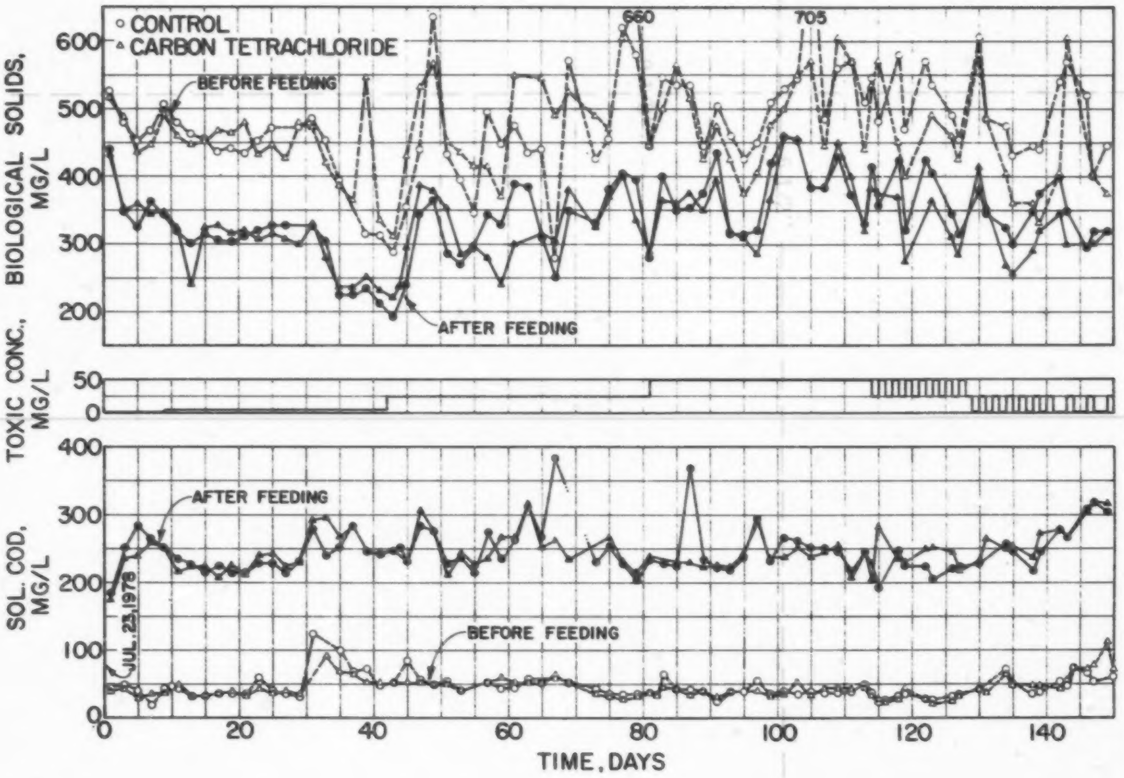

Figure 40. Operational results of batch control and carbon tetrachloride units.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

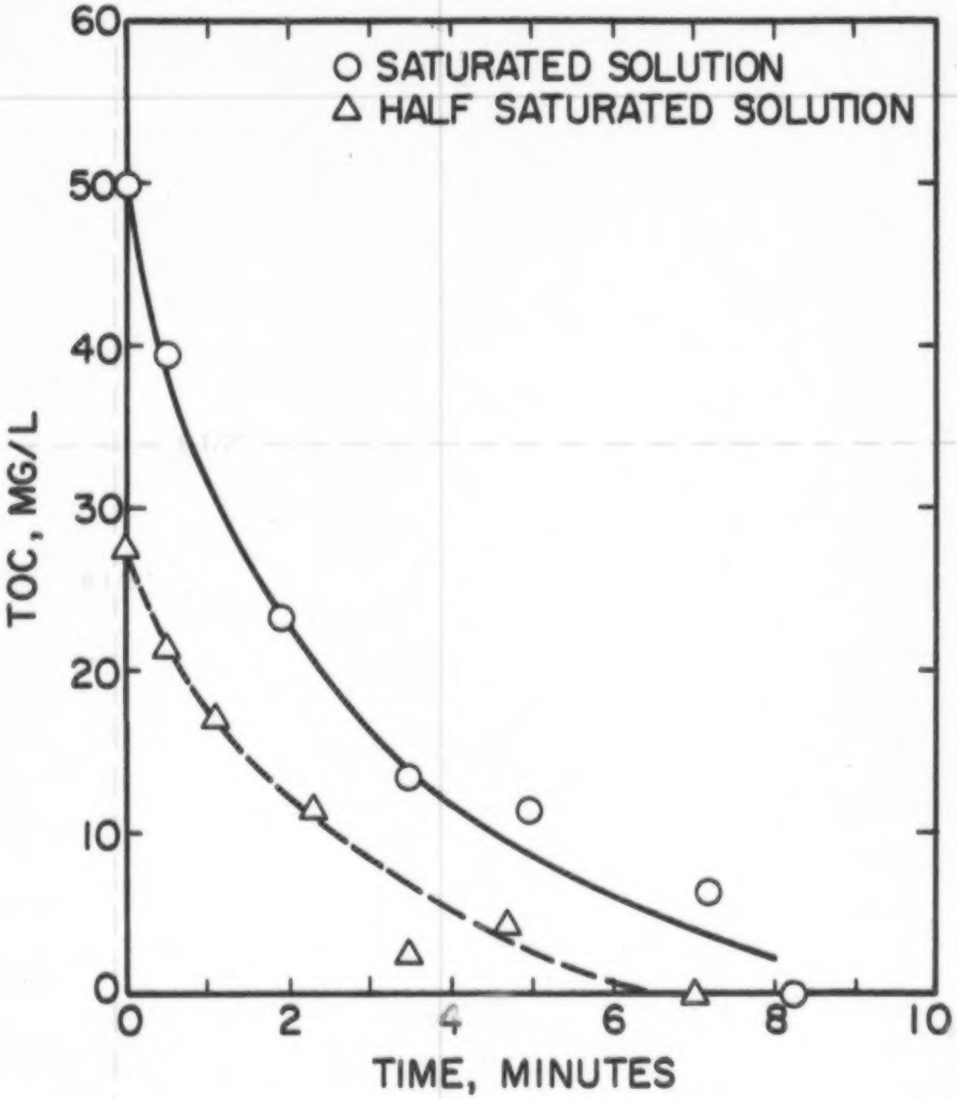

Figure 41. Stripping of carbon tetrachloride in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

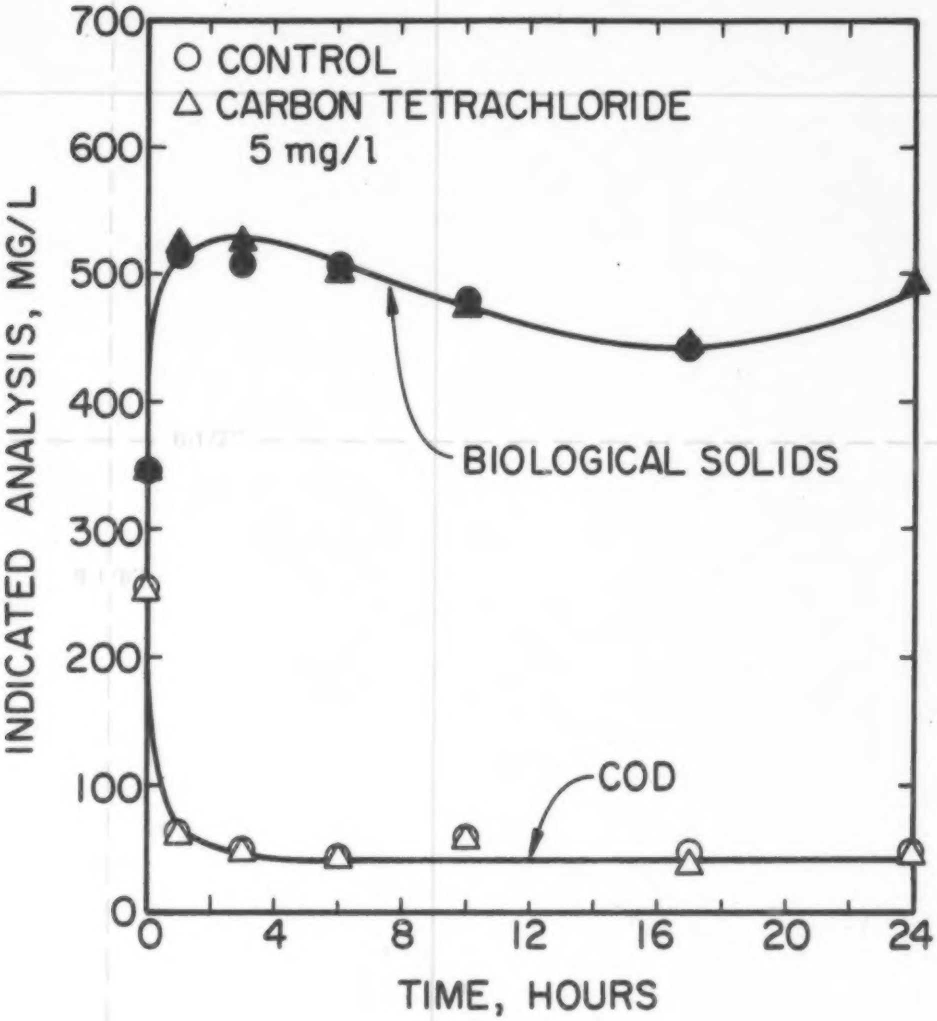

Figure 42. Growth and COD removal of carbon tetrachloride unit, dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

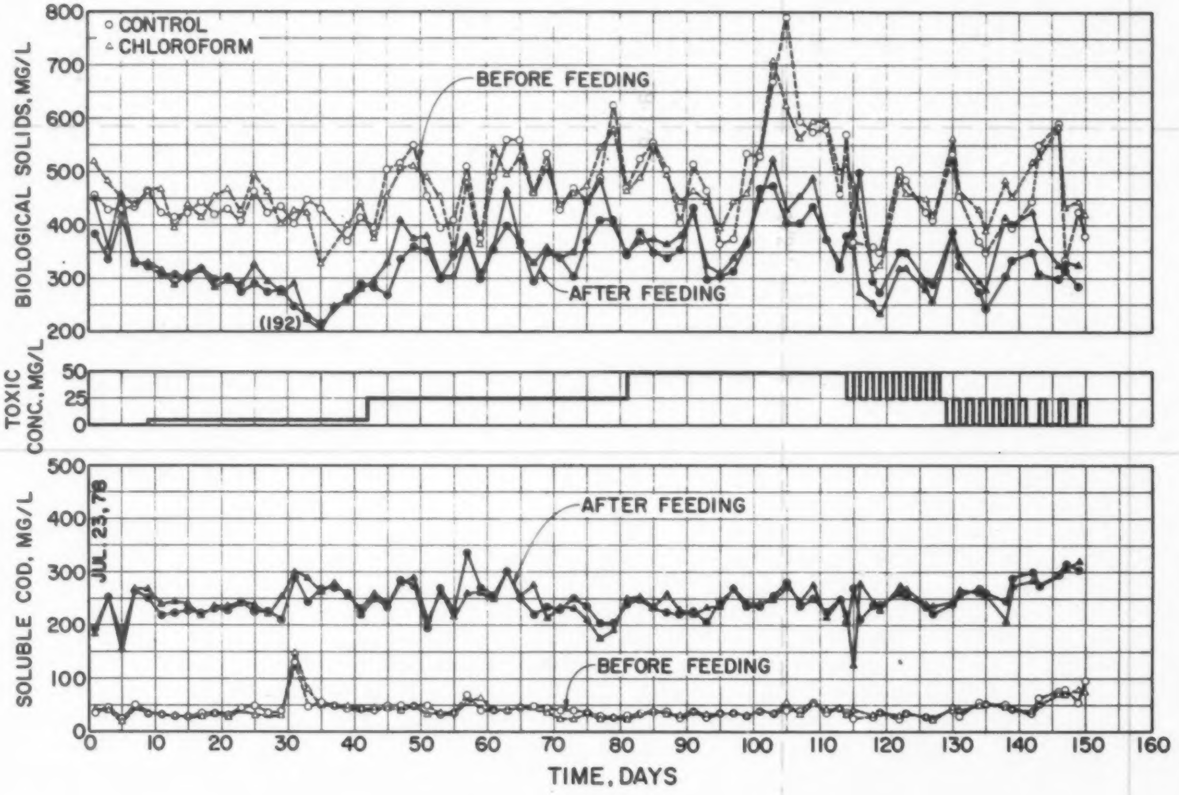

Figure 43. Operational results of batch control and chloroform units.

TABLE 11. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH CHLOROFORM AND TRICHLOROETHYLENE

Date	Parameter	CONTROL				CHLOROFORM				TRICHLOROETHYLENE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
7-24-78 to 8-1-78	N	5	5	5	5	5	5	5	5	5	5	5	5	No toxic compound added.
	X	38.8	228.4	444.0	358.4	36.4	226.0	472.8	384.4	39.6	213.4	462.4	375.2	
	σ	10.5	38.8	17.2	39.9	9.6	52.0	30.8	64.8	7.2	43.2	31.6	52.5	
	C.V.%	27.1	17.0	3.9	11.1	26.4	23.0	6.5	16.9	18.2	20.2	6.8	14.0	
	Range	24-52	180-264	428-468	324-416	20-44	156-268	440-520	328-460	28-45	163-256	424-504	320-440	
8-2-78 to 9-2-78	N	16	16	15	15	16	16	15	15	16	16	15	15	5 mg/1 toxic compound added.
	X	46.4	238.8	424.3	280.8	47.2	249.8	430.7	283.6	44.0	244.3	409.5	284.0	
	σ	24.1	22.8	21.3	30.4	29.9	22.9	40.3	36.1	23.0	22.2	45.2	35.3	
	C.V.%	51.9	9.6	5.0	10.8	63.3	9.2	9.4	12.7	52.2	9.1	11.0	12.4	
	Range	28-132	211-292	372-464	216-320	28-148	220-300	328-496	192-328	20-120	224-296	320-468	220-340	
9-3-78 to 10-12-78	N	20	20	20	20	19	20	20	20	19	20	20	20	25 mg/1 toxic compound added.
	X	42.4	248.8	482.5	360.1	38.7	244.2	475.2	378.6	45.7	249.5	453.4	338.2	
	σ	9.1	34.6	64.9	65.7	11.2	33.3	59.4	64.8	9.9	33.1	62.9	44.9	
	C.V.%	21.5	13.9	13.4	18.2	28.9	13.6	12.5	17.1	21.7	13.3	13.9	13.3	
	Range	28-68	195-336	375-625	270-410	24-64	176-304	355-580	296-485	28-70	160-309	328-600	260-400	
10-13-78 to 11-14-78	N	17	17	16	16	17	17	17	17	17	17	17	17	50 mg/1 toxic compound added.
	X	37.5	238.5	527.2	377.8	38.6	244.4	520.0	393.2	34.8	241.6	486.5	382.4	
	σ	6.9	19.7	107.2	56.4	7.1	18.0	80.1	60.1	4.7	21.8	69.9	61.1	
	C.V.%	18.4	8.3	20.3	14.9	18.4	7.4	15.4	15.3	13.6	9.0	14.4	16.0	
	Range	26-56	206-280	365-790	300-475	31-56	217-276	395-710	310-525	26-45	205-280	385-615	310-505	
11-15-78 to 12-20-78	N	19	19	18	17	19	19	19	18	19	19	19	18	Cyclic changes.
	X	47.0	262.3	431.9	311.2	47.3	257.6	456.0	329.7	42.6	243.5	454.5	343.1	
	σ	20.5	29.1	74.9	35.6	16.4	41.8	68.4	56.3	12.5	42.0	77.6	65.2	
	C.V.%	43.7	11.1	17.3	11.4	34.7	16.2	15.0	17.1	29.3	17.2	17.1	19.0	
	Range	24-96	212-316	335-590	245-500	24-80	127-320	320-585	235-425	24-72	131-304	320-615	245-470	

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

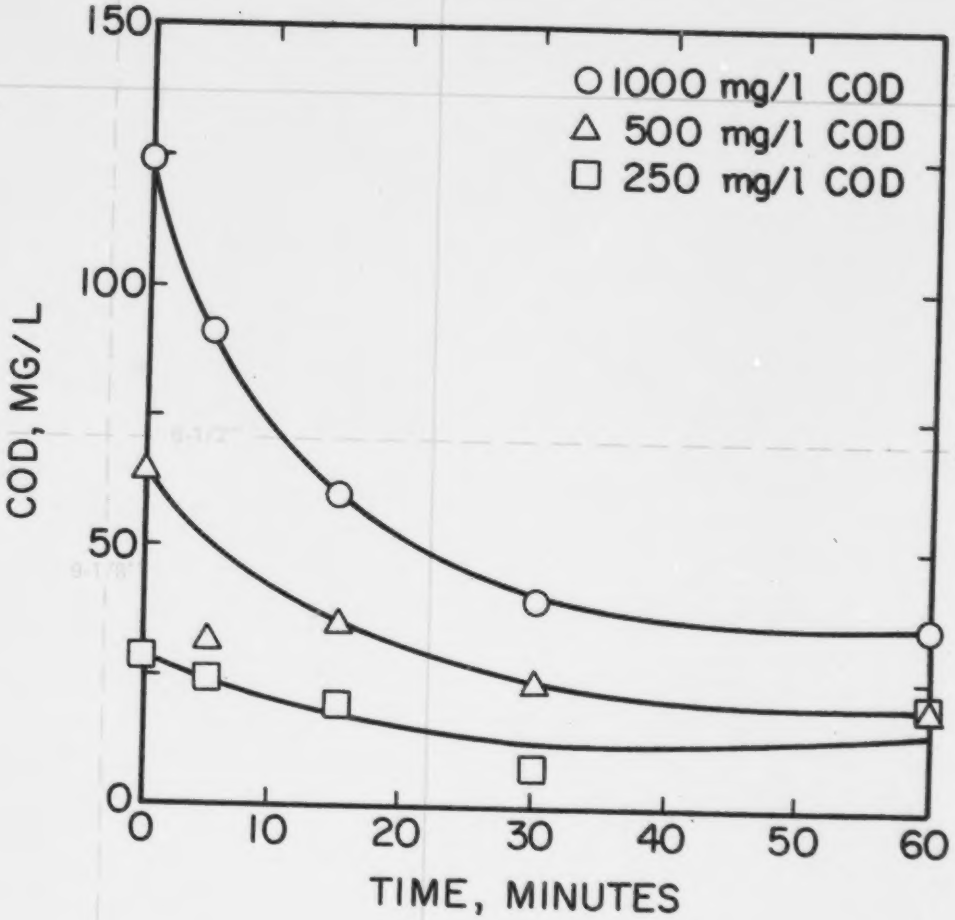

Figure 44. Stripping of chloroform in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

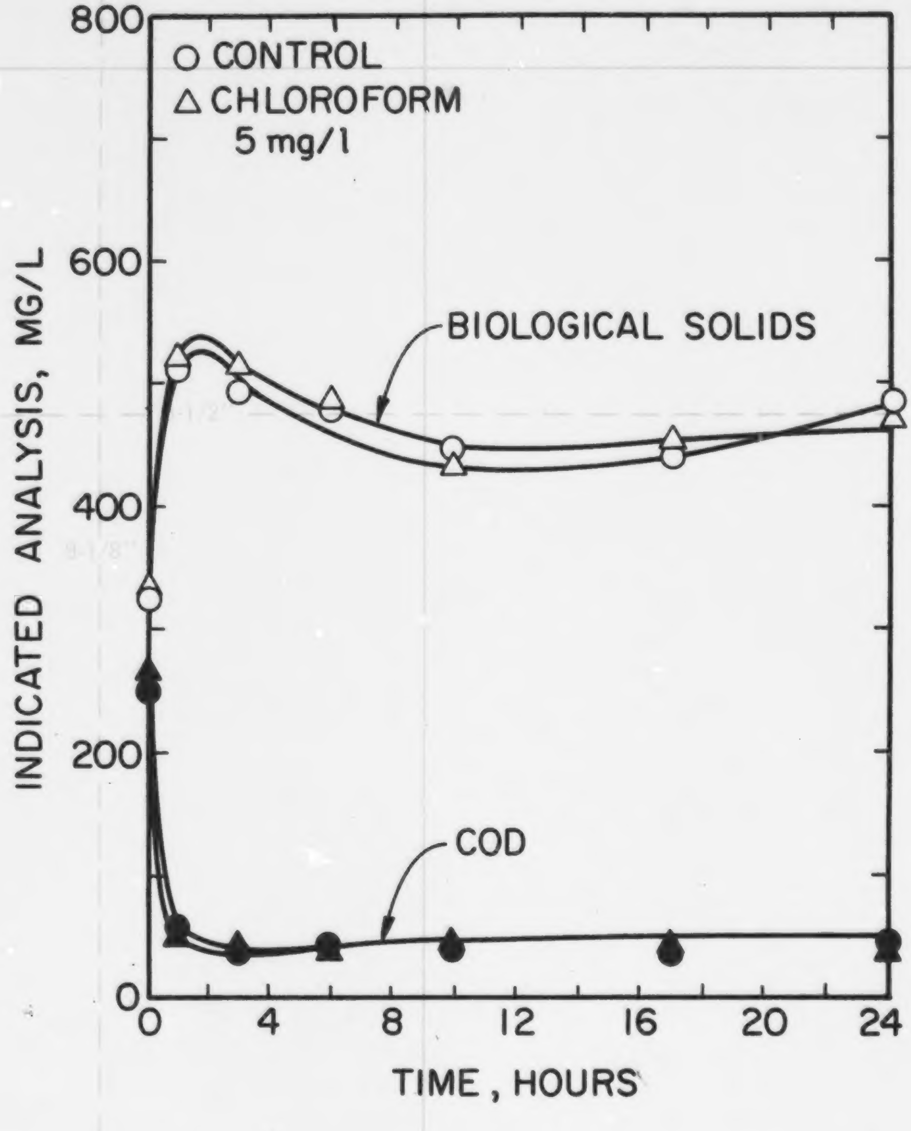

Figure 45. Growth and COD removal of batch chloroform unit, dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

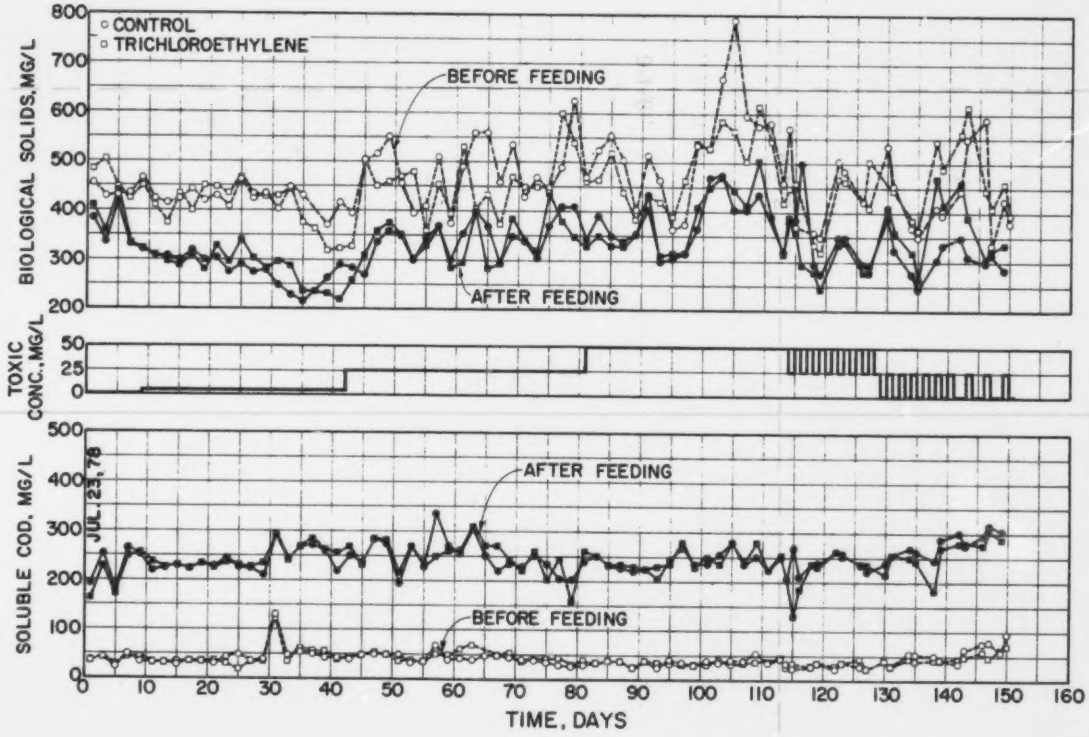

Figure 46. Operational results of batch control and trichloroethylene units.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

was dosed with trichloroethylene compared favorably with the performance of the control system. As the dosage was increased through 25 to 50 mg/l, there was some evidence for slightly higher biomass concentrations in the control than in the dosed system. The general equivalence of performance in regard to soluble COD in the supernatant and the slightly greater biomass concentration in the control, compared to the dosed unit, is verified in the statistical analysis shown in Table 11.

Figure 47 shows that trichloroethylene is rapidly stripped from the system. Batch rate studies on COD removal and sludge accumulation made at various times during the test period indicated that the dosed unit and the control unit behaved similarly. Figure 48 shows the results when the dosage was changed from 0 to 5 mg/l trichloroethylene. Studies at higher dosages provided similar results. Periodic settling tests made during this run indicated that the suspended solids concentration in the supernatant of the unit dosed with trichloroethylene was somewhat higher than for the control. Only trace amounts of trichloroethylene were present in the supernatant, based on a few samples taken during the experimental period at each dosage level.

Chlorobenzene

The results shown in Figure 49 indicate that chlorobenzene at varying concentrations in the feed had little or no stressful effect upon the behavior of the batch activated sludge system in regard to soluble residual COD and mixed liquor suspended solids. This conclusion is verified by the results of the statistical analysis shown in Table 12. The results of a stripping test on chlorobenzene are shown in Figure 50 and it is seen that the compound is very rapidly stripped from the system.

A study of rate of substrate removal made on the day the chlorobenzene concentration was changed from 0 to 5 mg/l in the feed indicated that it had little or no effect upon the biomass concentration or the concentration of soluble COD in the system (Figure 51). Studies made when the chlorobenzene concentration was increased to higher concentrations gave similar results. Results from several samples analyzed for suspended solids concentration of supernatant after one hour of settling during periods of various dosages employed indicated little or no effect of chlorobenzene on supernatant quality. Chlorobenzene was not detected in the effluent.

Tetrachloroethylene

Compared to the same control system used to assess the effects of chlorobenzene the dosages with tetrachloroethylene yielded essentially similar results (Figure 52). That is, neither compound had a deleterious effect upon the system at the concentrations studied in this experimentation. This result is verified in the statistical analyses which are shown in Table 12. However, it should be noted that the coefficient of variation for soluble residual COD was consistently higher in the test unit than in the control.

As seen from Figure 53, tetrachlorethylene is rapidly stripped under

EPA-287 (Cin.)
(4-76)

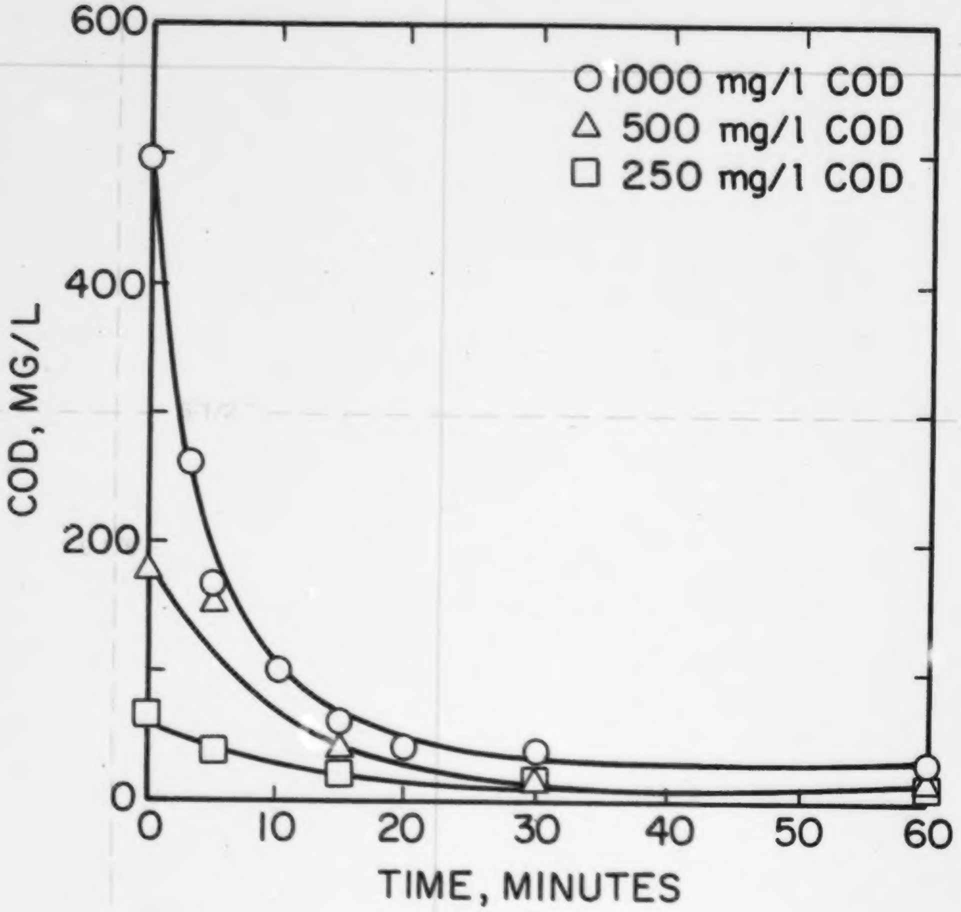

Figure 47. Stripping of Trichloroethylene in batch growth reactor.

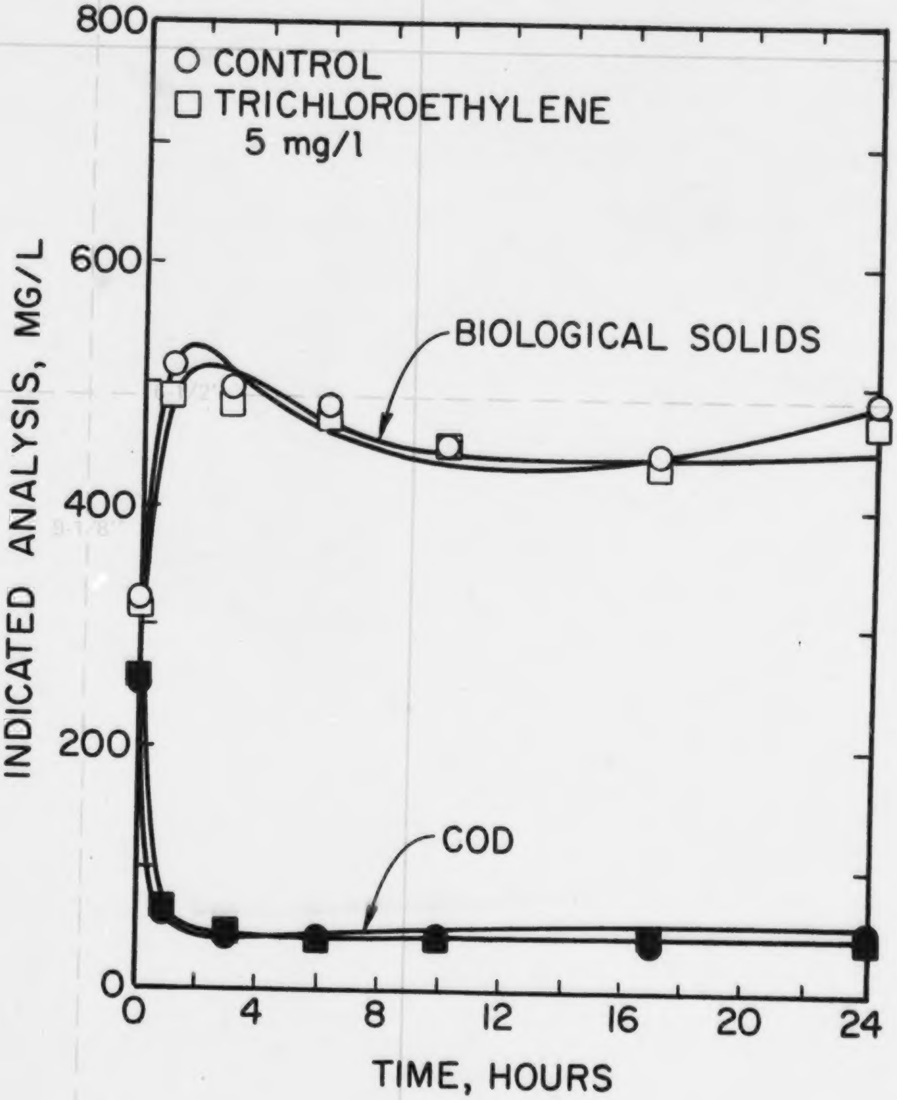

Figure 48. Growth and COD removal of trichloroethylene unit, dosage=5 mg/1.

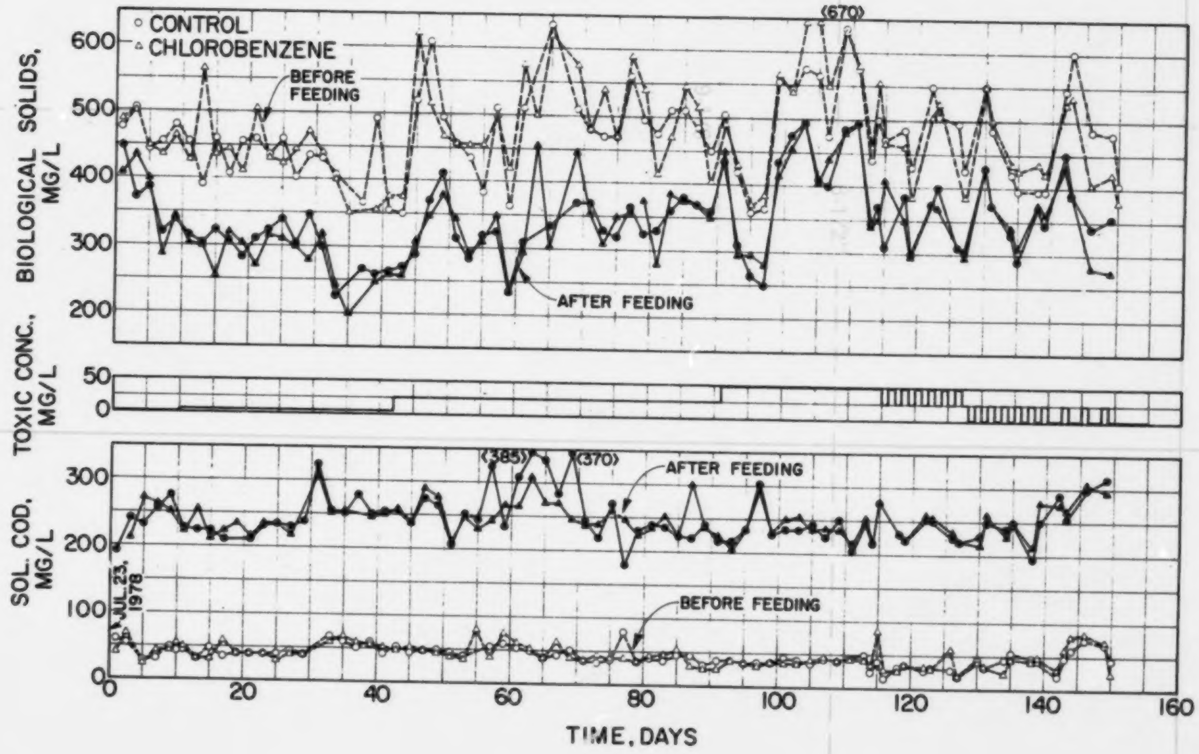

Figure 49. Operational results of batch control and chlorobenzene units.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 12. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH CHLOROBENZENE AND TETRACHLOROETHYLENE

Date	Parameter	CONTROL				CHLOROBENZENE				TETRACHLOROETHYLENE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
7-24-78 to 8-1-78	N	5	5	5	5	5	4	5	5	5	5	5	5	No toxic compounds added.
	X	44.8	239.8	472.0	373.6	44.4	250.0	467.2	375.2	39.6	238.2	484.0	399.8	
	σ	14.3	30.9	23.2	49.4	16.1	26.6	26.7	59.1	9.6	30.0	22.4	61.4	
	C.V.%	31.9	12.9	4.9	13.2	36.3	10.6	5.7	15.8	24.2	12.6	4.6	15.4	
	Range	28-61	193.276	444-504	320-448	24-69	212-272	436-500	288-436	28-49	191-264	460-520	334-497	
8-2-78 to 9-3-78	N	16	15	15	15	16	14	15	15	15	16	16	16	5 mg/l toxic compound added.
	X	45.9	243.7	428.9	298.9	47.3	241.0	425.6	282.4	45.5	256.0	417.8	284.0	
	σ	9.7	28.9	37.0	32.6	11.7	24.6	51.0	35.0	17.9	37.6	32.3	31.8	
	C.V.%	21.1	11.9	8.6	10.9	24.7	10.2	12.0	12.4	39.3	14.7	7.7	11.2	
	Range	32-68	212-324	356-492	228-348	32-68	212-308	352-564	200-320	28-96	220-376	332-460	196-344	
9-4-78 to 10-12-78	N	19	20	18	18	20	20	19	19	20	19	19	19	25 mg/l toxic compound added.
	X	47.4	268.8	485.1	326.8	48.6	254.4	503.7	335.0	43.2	241.4	526.6	352.2	
	σ	10.9	52.9	73.8	41.7	12.8	23.5	70.2	55.3	14.0	34.2	102.4	45.9	
	C.V.%	23.0	19.7	15.2	12.8	26.3	9.2	13.9	16.5	32.4	14.2	19.4	13.0	
	Range	33-80	180-385	352-635	235-412	36-80	212-309	376-620	235-455	20-92	199-317	388-750	255-415	
10-13-78 to 1-14-78	N	17	17	17	17	17	17	17	17	17	17	17	17	50 mg/l toxic compound added.
	X	39.4	234.8	498.2	384.7	37.9	242.5	517.9	386.8	43.9	242.1	529.7	385.0	
	σ	6.0	21.7	75.0	69.7	7.2	24.8	89.4	64.5	15.7	24.6	101.2	52.5	
	C.V.%	15.2	9.2	15.1	18.1	19.0	10.2	17.3	16.7	35.8	10.2	19.1	13.6	
	Range	25-49	205-304	360-635	250-495	26-54	206-302	370-670	280-495	32-99	211-304	390-785	295-465	
11-15-78 to 12-20-78	N	20	17	18	17	20	17	17	16	20	17	17	16	Cyclic changes.
	X	40.8	250.8	473.1	359.4	45.2	253.0	456.2	353.8	44.4	251.4	444.7	322.2	
	σ	15.8	31.2	61.8	44.9	21.1	29.1	57.0	50.6	18.8	39.3	65.8	38.0	
	C.V.%	38.7	12.4	13.1	12.5	46.7	11.5	12.5	14.3	42.3	15.6	14.8	11.8	
	Range	16-76	196-316	395-600	290-450	20-86	216-308	380-550	275-430	16-88	135-308	345-560	260-390	

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

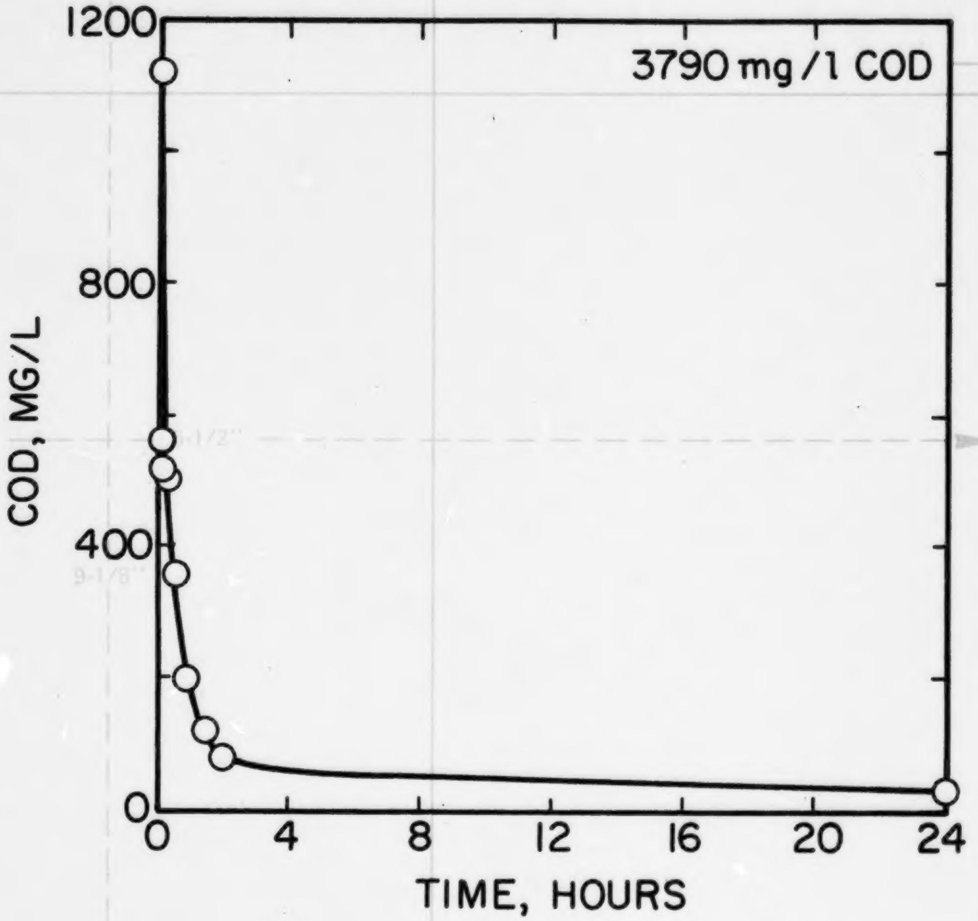

Figure 50. Stripping of chlorobenzene in the batch growth reactor.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

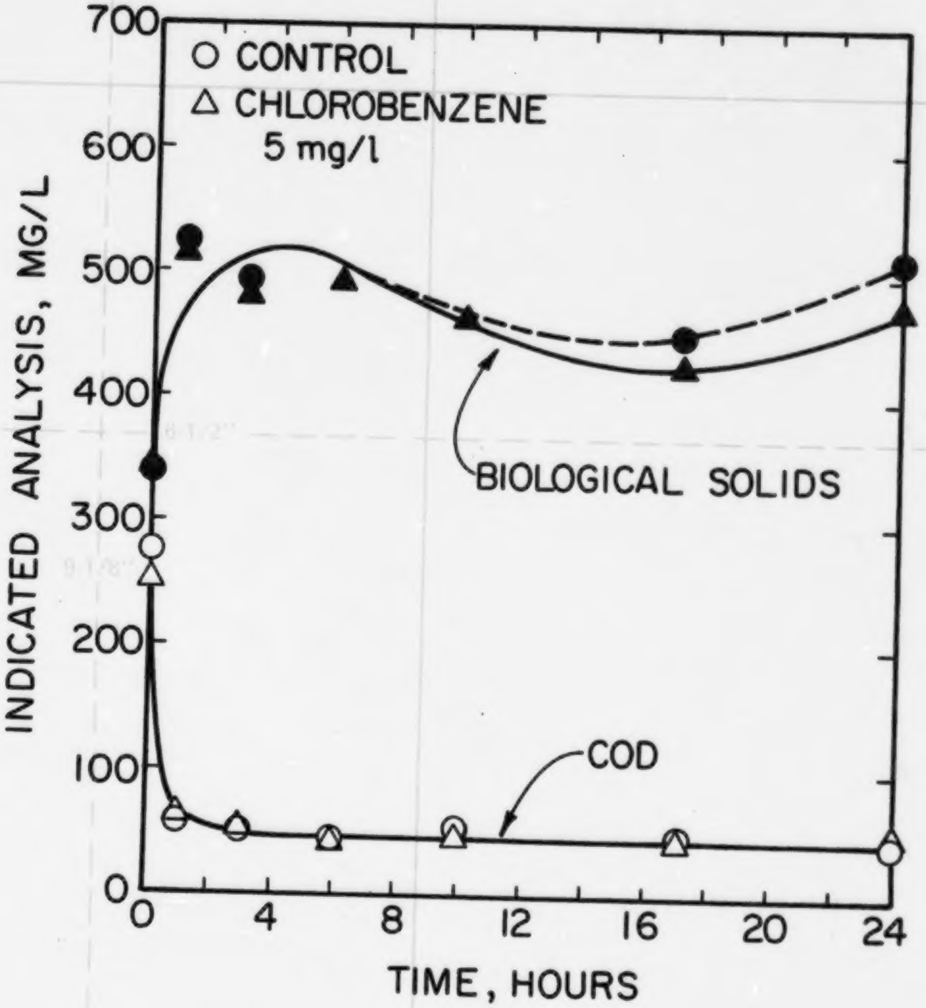

Figure 51. Growth and COD removal of batch chlorobenzene unit, dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-78)

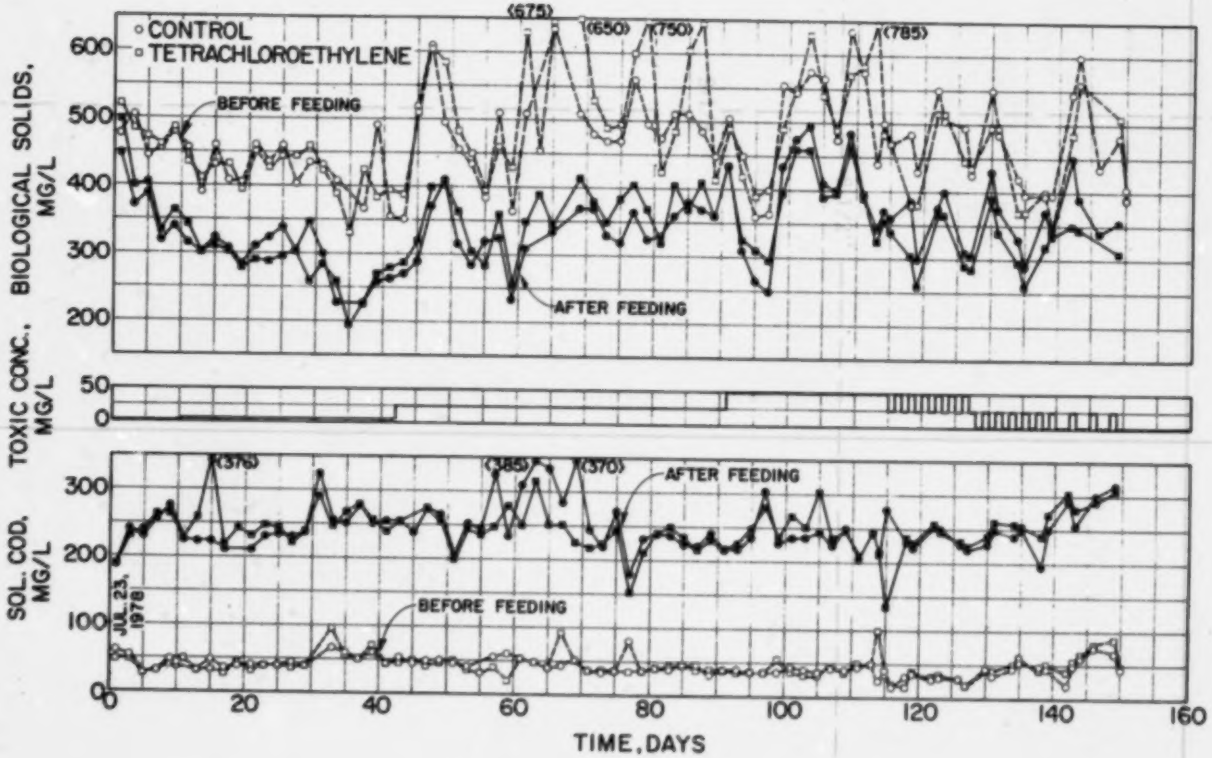

Figure 52. Operational results of batch control and tetrachloroethylene units.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

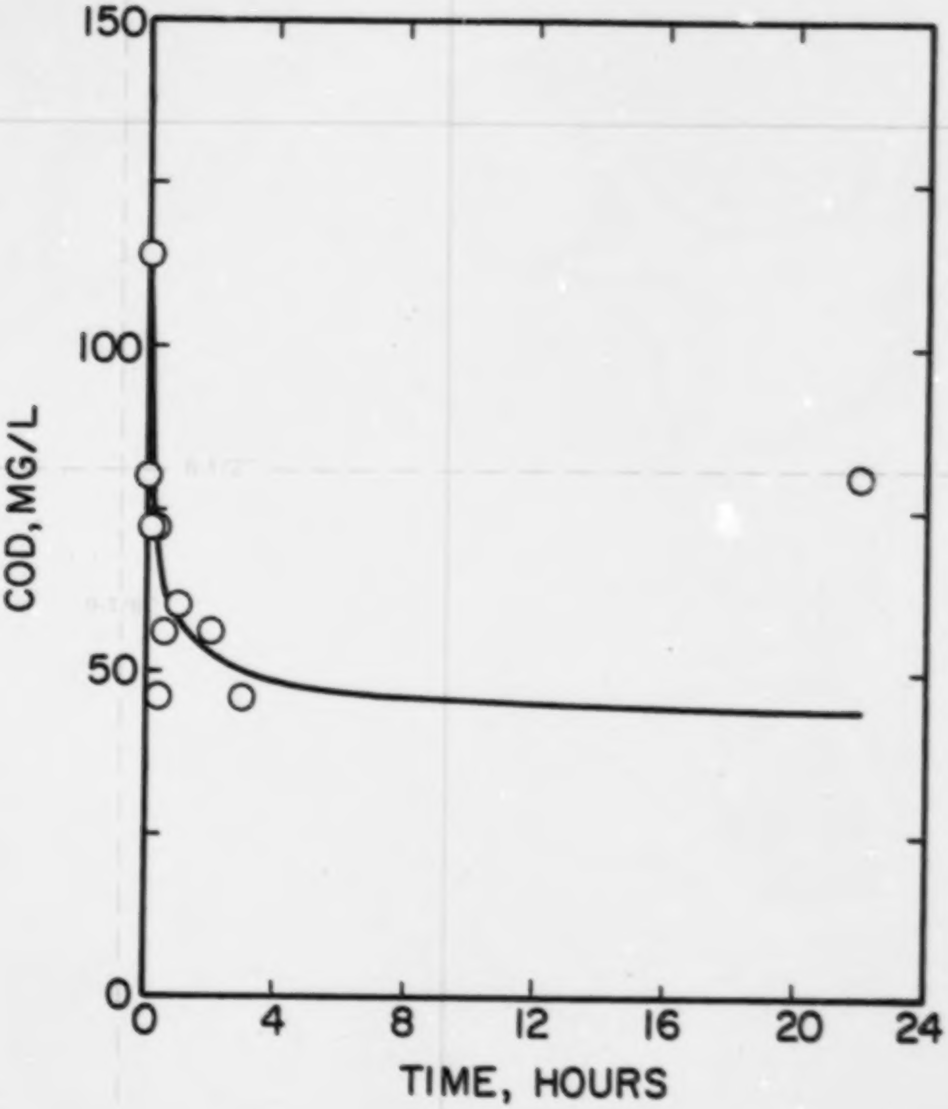

Figure 53. Stripping of tetrachloroethylene in the batch growth reactor.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

the conditions of these experimentations. Figure 54 shows the results when the tetrachloroethylene concentration in the feed was changed from 5 to 25 mg/l. It is seen that this dosage level of the test compound had little or no effect on the rates of COD removal and biomass production. Experiments run at higher dosage levels gave similar results. Only one analysis of the supernatant for the test compound was made; at a dosage of 50 mg/l in the feed, the effluent concentration was registered as <0.18 mg/l.

4-Chloro,3-methylphenol

Increasing dosages of 4-chloro,3-methylphenol to a batch pilot plant operating on municipal sewage led to slightly higher values of COD and lower biomass concentrations as the dosage was increased (see Figure 55). The statistical analyses (shown in Table 13)verify the trends shown graphically in Figure 55.

The compound was not stripped under conditions of these experimentations (Figure 56). When the dosage was increased from 0 to 5 mg/l and samples were taken to assess the rate of COD removal and biological solids production there was no apparent effect; however, when the dosage was increased from 5 to 25 mg/l there was a decrease in the rate of COD removal (Figure 57). Comparison of supernatant suspended solids concentration in control and test units indicated higher values in the unit dosed with 4-chloro,3-methylphenol.

Ethylbenzene

The results shown in Figure 58 indicate that ethylbenzene had no effect on the soluble COD nor the biomass in the batch activated sludge system. The statistical analyses shown in Table 14 indicated that there was only a minor effect due to ethylbenzene and this occurred only at the higher dosage levels.

It can be seen in Figure 59 that ethylbenzene is rapidly stripped under the aeration conditions existing during the present experimentation. A semilogarithmic plot of these data indicate that the compound strips in accordance with first order decreasing-rate kinetics. Figure 60 shows the COD and biomass accumulation when the dosage was changed from 5 to 25 mg/l in the feed and it is seen that there was no effect on the growth and substrate removal parameters. There was no evidence that the test compound interfered with settling of the sludge based on comparison of supernatant suspended solids concentrations in the test and control units.

1,2-Dichloroethane

The results shown in Figure 61 indicate that 1,2-dichloroethane, at the dosages administered, had essentially no effect on the residual soluble COD nor on biological solids production in the batch activated sludge system. This conclusion is verified by the results of the statistical analysis shown in Table 15.

The test compound is strippable at the airflow rates employed in these

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

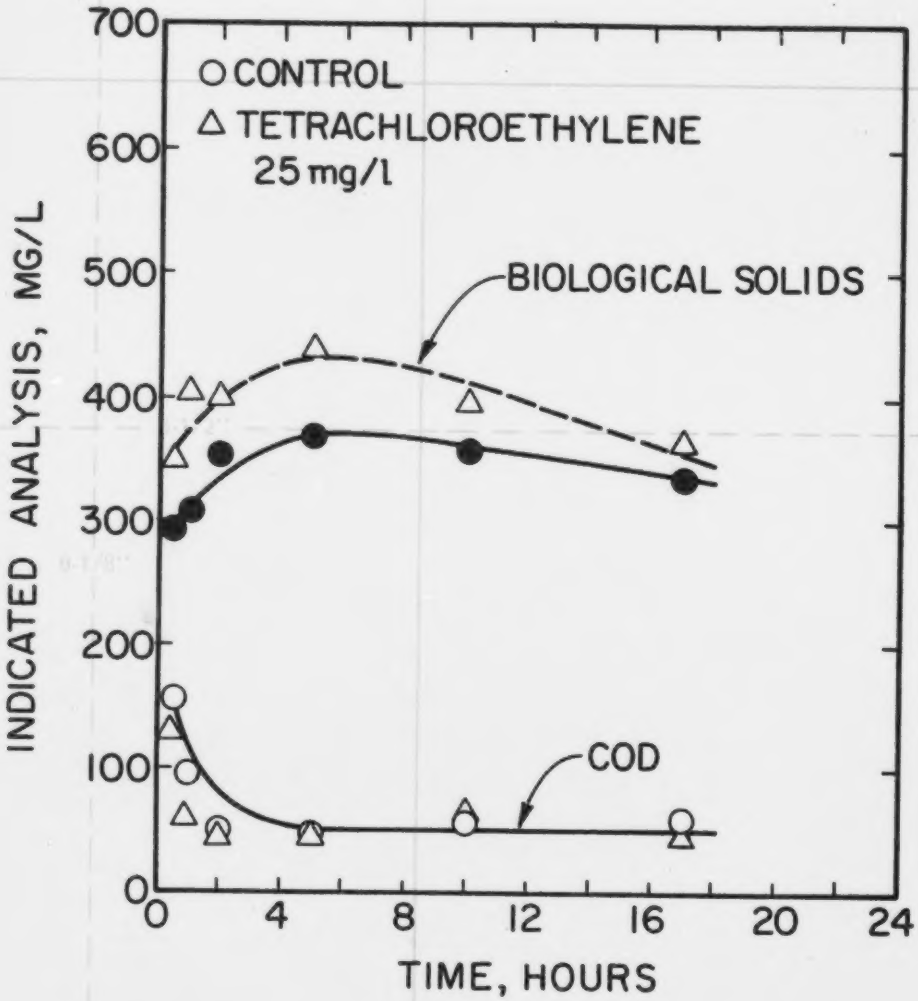

Figure 54. Growth and COD removal of tetrachloroethylene unit, dosage=25 mg/l.

PAGE NUMBER
EPA-287 (Cin.)
(4-75)

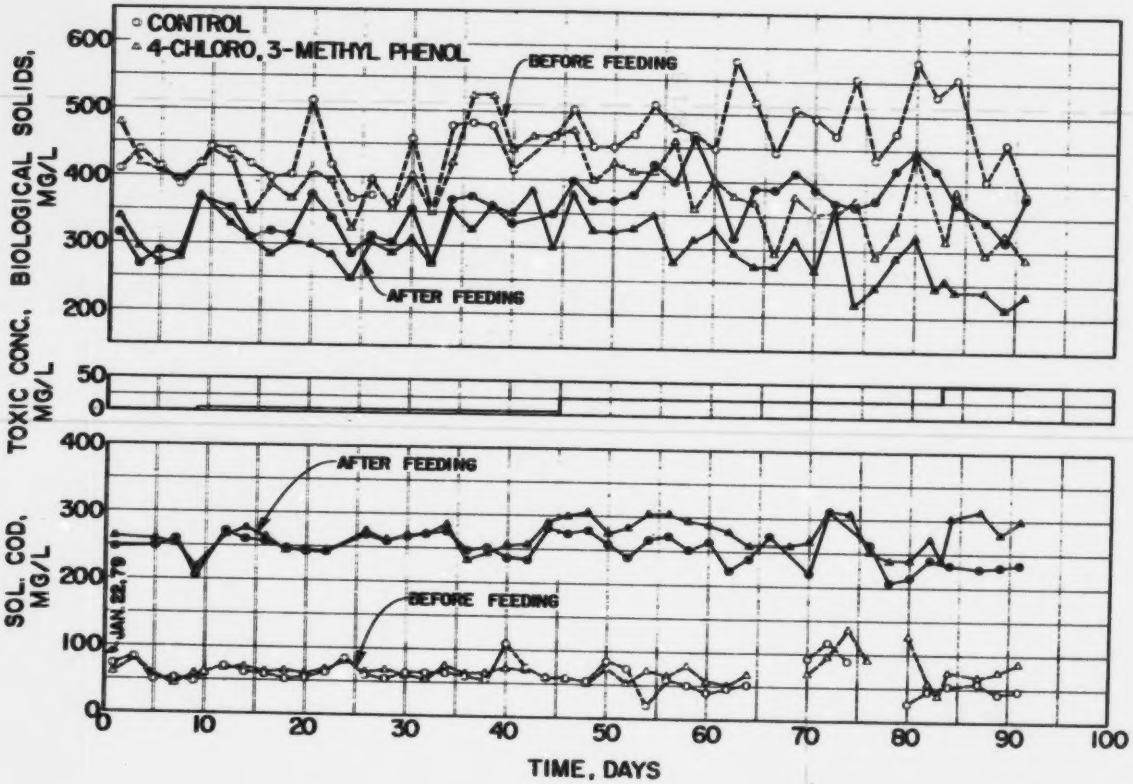

Figure 55. Operational results of batch control and 4-chloro, 3 methyl phenol units.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE

DROPPED HEAD: BEGIN SECTIONS HERE

TOP OF IMAGE AREA

CENTER OF PAGE

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

TABLE 13. STATISTICAL ANALYSIS OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGE DOSED WITH 4-CHLORO, 3-METHYL PHENOL

Date	Parameter	CONTROL				4 CHLORO, 3-METHYL PHENOL								Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1/23/79 to 1/31/79	N	5	4	5	5	5	4	5	5					No toxic compound added.
	X	62.0	240.5	415.0	306.0	60.8	248.2	425.0	311.4					
	σ	16.7	23.7	18.0	39.3	13.7	20.0	32.4	43.2					
	C.V.%	26.9	9.8	4.3	12.8	22.5	8.1	7.6	13.9					
	Range	48-86	206-260	390-440	270-370	44-82	219-263	395-480	270-372					
2/1/79 to 3/8/79	N	18	16	18	17	18	16	18	17					5 mg/l toxic compound added.
	X	64.6	257.8	430.7	336.6	66.2	262.5	414.7	312.9					
	σ	12.9	14.5	46.9	32.0	6.1	16.2	56.6	34.4					
	C.V.%	20.0	5.6	10.9	9.5	9.3	6.2	13.6	11.0					
	Range	52-108	234-282	355-515	275-380	56-80	236-292	325-525	250-385					
3/9/79 to 4/14/79	N	15	17	19	19	16	17	18	19					25 mg/l toxic compound added.
	X	61.8	253.9	494.2	395.1	75.9	282.0	385.0	302.3					
	σ	26.1	27.8	44.4	33.0	25.9	23.9	51.0	41.8					
	C.V.%	42.3	11.0	9.0	8.4	34.2	8.5	13.3	13.8					
	Range	20-117	208-280	435-580	317-465	52-137	240-311	290-475	220-380					
4/15/79 to 4/23/79	N	4	4	4	4	5	5	5	5					50 mg/l toxic compound added.
	X	50.5	233.0	451.2	352.5	68.8	287.8	325.0	237.4					
	σ	7.0	2.6	76.1	29.0	17.7	27.9	39.8	15.0					
	C.V.%	13.9	1.1	16.9	8.2	25.7	9.7	12.3	6.3					
	Range	42-54	230-236	385-555	315-380	40-88	243-314	290-390	215-257					

EPA-287 (Cin.)
(4-76)

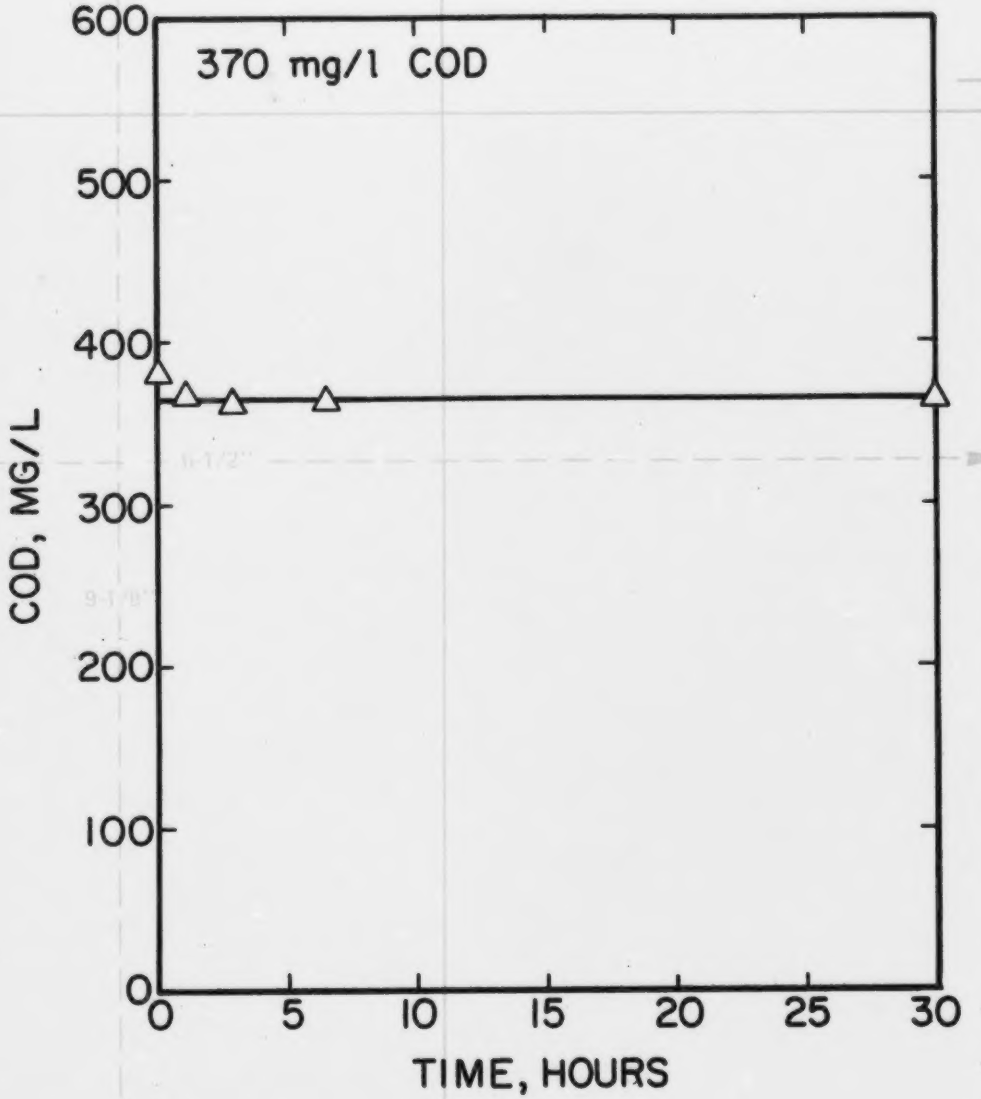

Figure 56. Stripping of 4-chloro, 3-methyl phenol in the batch growth reactor.

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

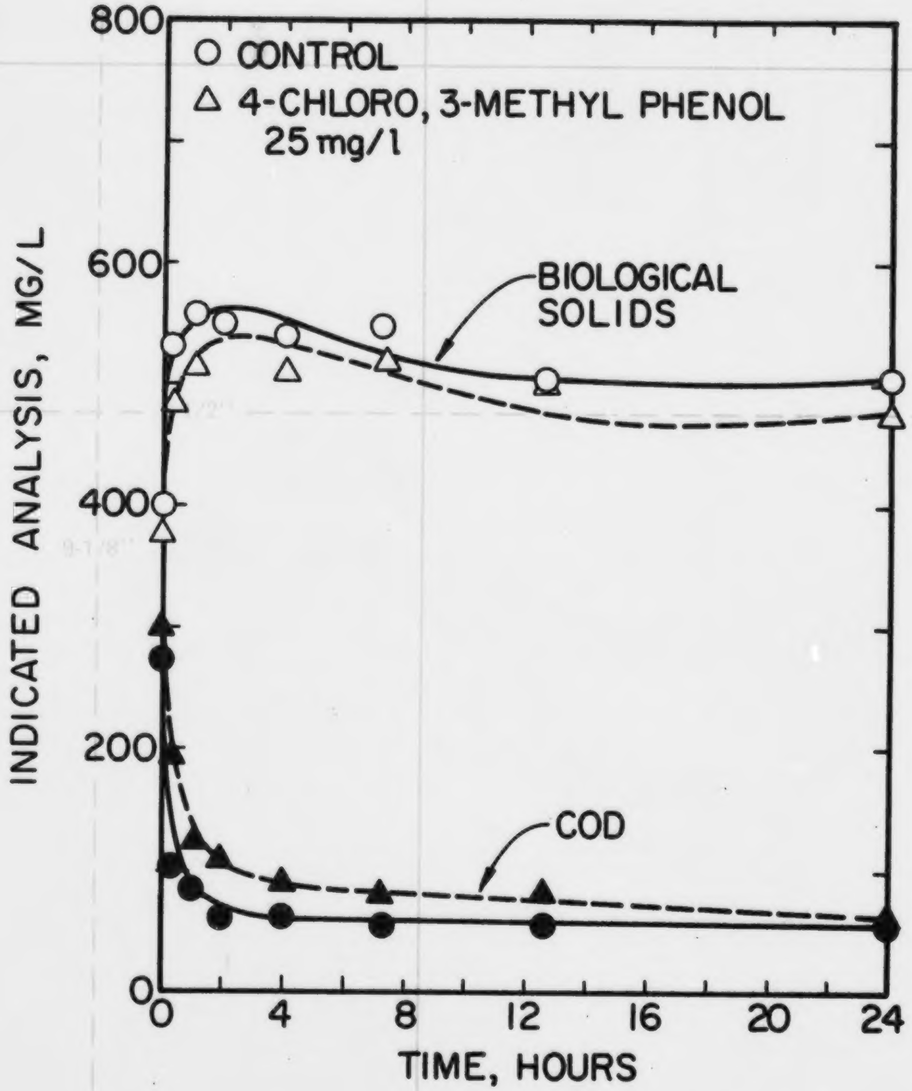

Figure 57. Growth and COD removal of 4-chloro,3-methyl phenol unit at 25 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

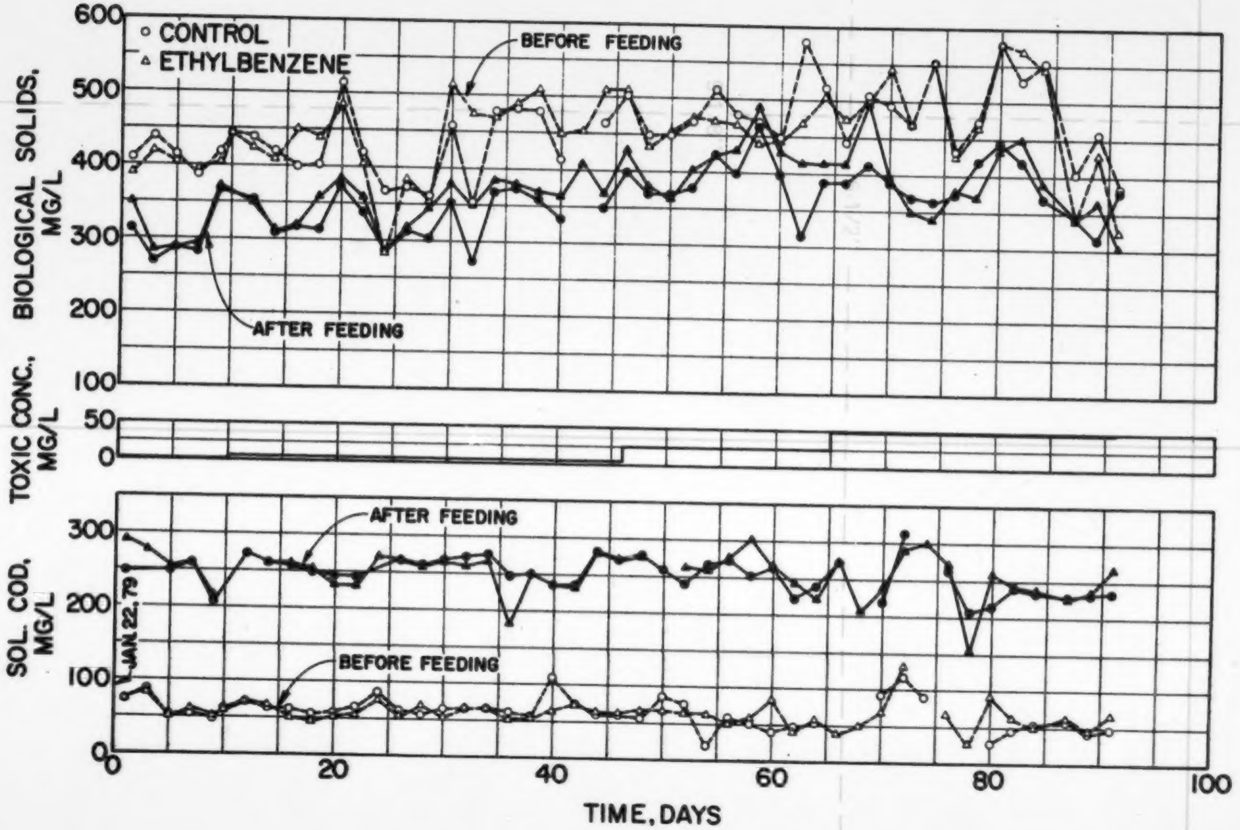

Figure 58. Operational results of batch control and ethylbenzene units.

TABLE 14. STATISTICAL ANALYSIS OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGE DOSED WITH ETHYLBENZENE

Date	Parameter	CONTROL				ETHYLBENZENE								Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1/23/79 to 1/31/79	N	5	4	5	5	5	5	5	5					No toxic compound added.
	X	62.0	240.5	415.0	306.0	63.6	259.4	403.0	319.0					
	σ	16.7	23.7	18.0	39.3	13.5	28.4	11.5	40.8					
	C.V.%	26.9	9.8	4.3	12.8	21.3	14.0	2.9	12.8					
	Range	48-86	206-260	390-440	270-370	51-82	215-290	390-420	285-375					
2/1/79 to 3/8/79	N	18	16	18	17	18	16	18	17					5 mg/l toxic compound added.
	X	64.6	257.8	430.7	336.6	61.0	251.1	441.9	356.6					
	σ	12.9	14.5	46.9	32.0	8.9	23.2	58.8	30.3					
	C.V.%	20.0	5.6	10.9	9.5	14.6	9.2	13.3	8.5					
	Range	52-108	234-282	355-515	275-380	44-76	184-280	285-515	288-410					
3/9/79 to 3/28/79	N	10	10	10	10	10	9	10	10					25 mg/l toxic compound added.
	X	55.4	257.5	489.0	391.7	61.0	265.3	467.0	418.5					
	σ	18.2	18.6	41.6	38.5	11.6	22.3	25.3	35.3					
	C.V.%	32.9	7.2	8.5	9.8	18.8	8.4	5.4	8.0					
	Range	20-84	222-280	450-580	317-465	40-84	224-304	435-510	365-490					
3/29/79 to 4/23/79	N	9	11	13	13	10	13	13	13					50 mg/l toxic compound added.
	X	63.9	243.0	484.6	384.6	68.0	246.9	478.8	387.3					
	σ	29.1	31.0	59.9	34.7	29.0	38.0	82.7	51.8					
	C.V.%	45.5	12.8	12.4	9.0	42.6	15.4	17.3	13.4					
	Range	28-117	208-315	385-555	315-445	28-135	156-299	325-580	305-495					

BEGIN LAST LINE OF TEXT

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

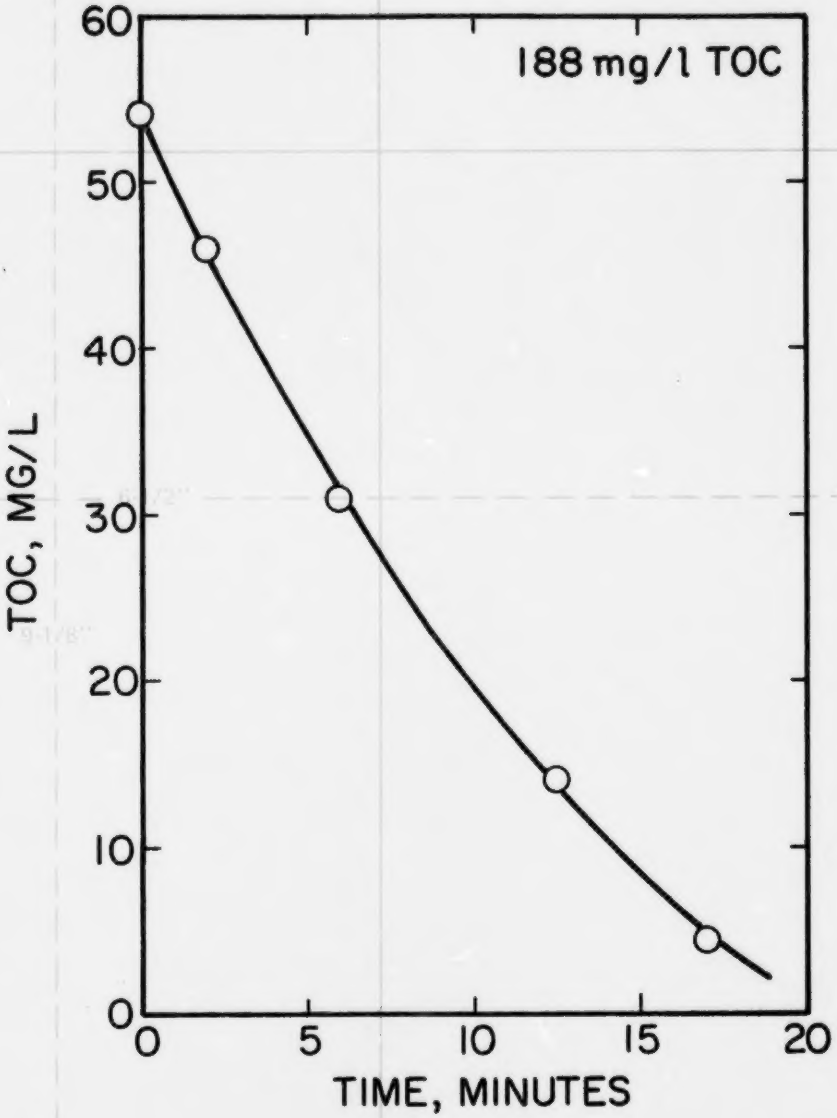

Figure 59. Stripping of ethylbenzene in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-75)

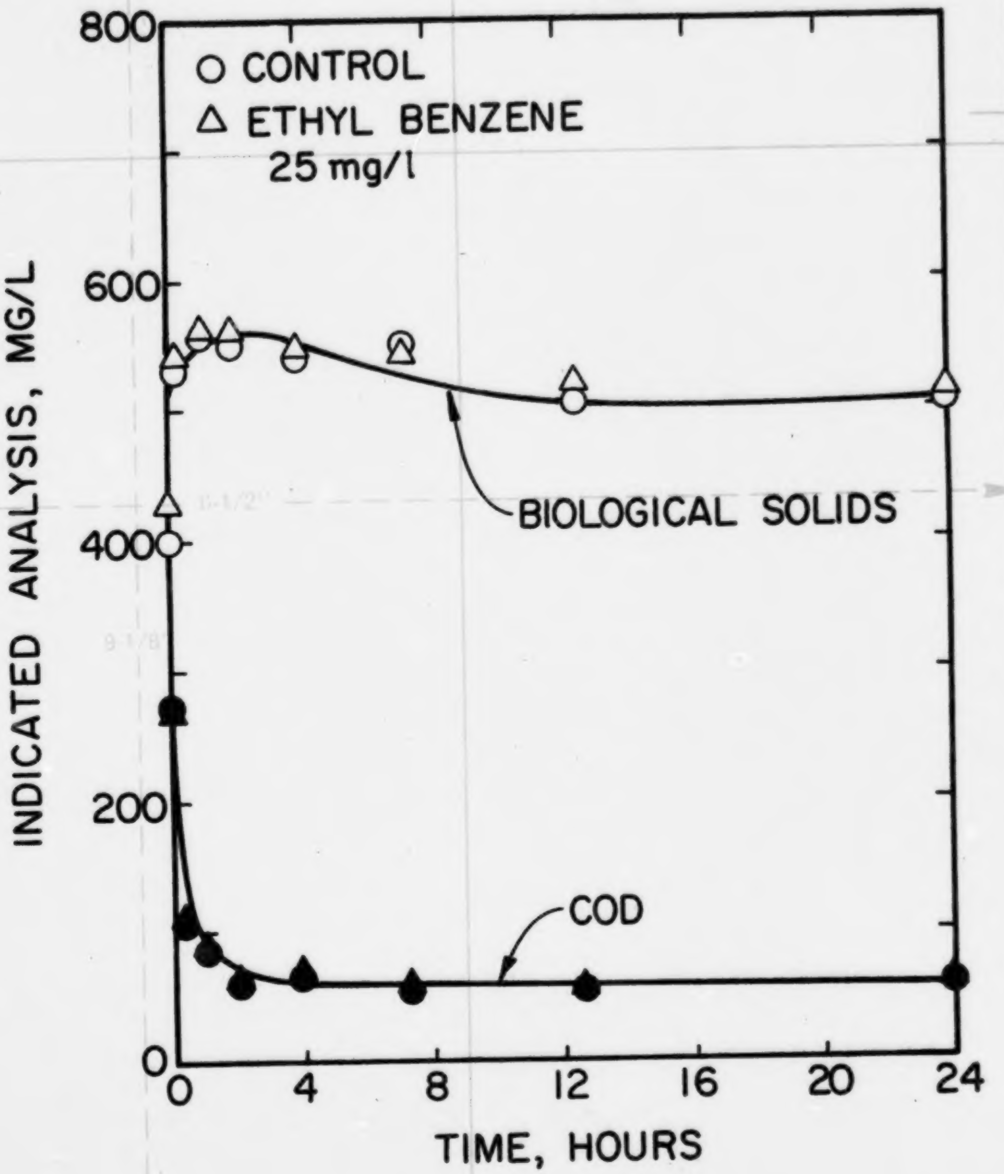

Figure 60. Growth and COD removal of ethylbenzene unit, dosage=25 mg/l.

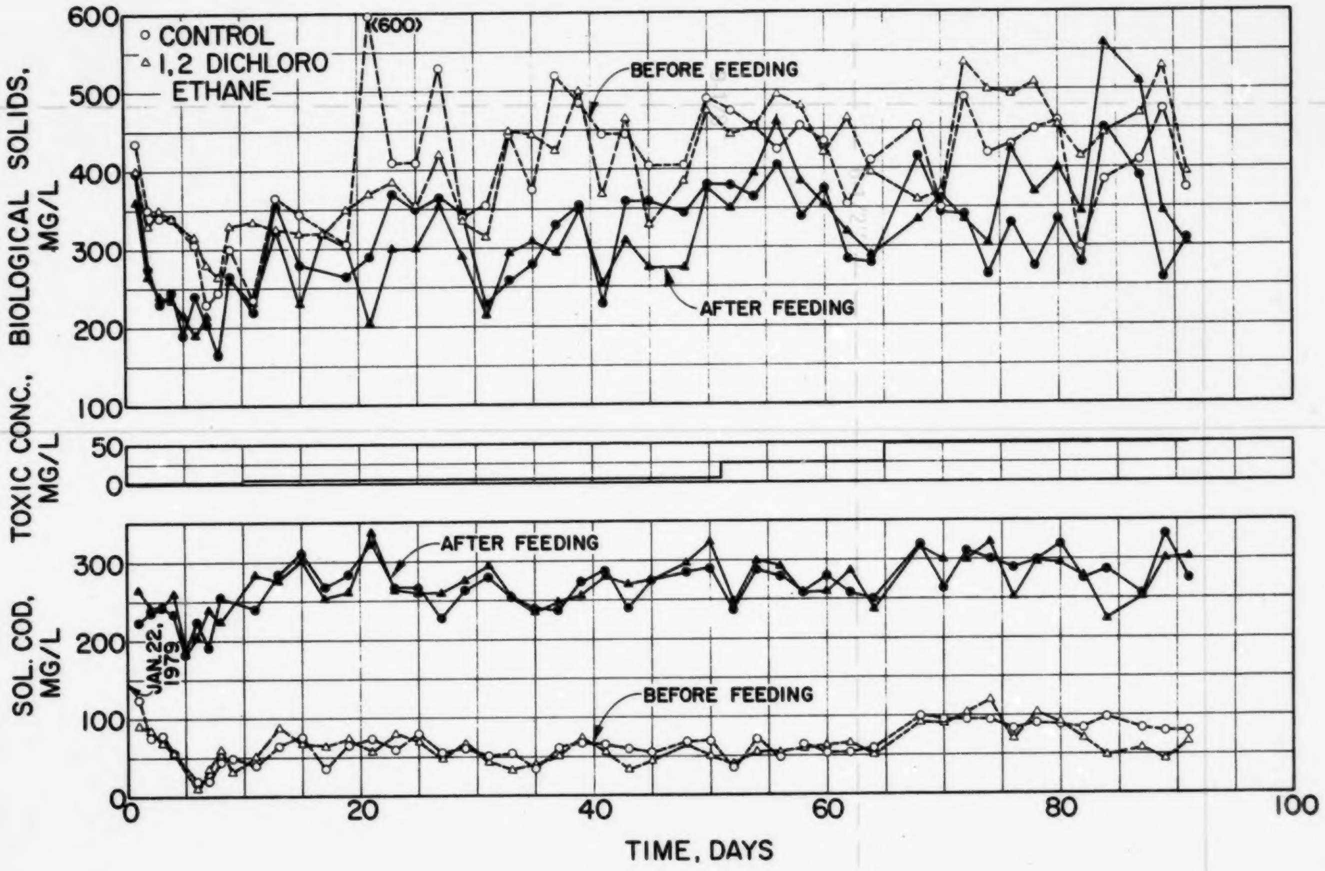

Figure 61. Operational results of batch control and 1,2-dichloroethane units.

EPA-287 (Cin.)
(4-76)

TABLE 15. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH 1,2 DICHLOROETHANE AND 1,1,2 TRICHLOROETHANE

Date	Parameter	CONTROL				1,2 DICHLOROETHANE				1,1,2 TRICHLOROETHANE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1/23/79 to 2/1/79	N	8	8	8	9	8	8	8	9	8	8	8	9	No toxic compound
	X	58.2	224.5	318.0	245.7	54.5	233.0	326.1	238.9	74.0	250.8	370.2	267.2	
	σ	34.4	24.3	64.8	66.5	27.2	27.1	42.0	54.9	42.4	36.9	59.8	34.6	
	C.V.%	59.0	10.8	20.4	27.1	49.9	11.6	12.9	23.0	57.3	14.7	16.1	13.0	
	Range	20-124	186-256	230-435	190-396	10-90	184-264	264-400	170-360	48-172	196-304	325-505	210-320	
2/2/79 to 3/8/79	N	18	18	17	17	18	18	18	18	18	18	18	18	5 mg/l toxic compound added.
	X	59.3	268.4	412.6	308.5	58.2	272.0	378.6	324.4	58.2	270.3	439.2	349.2	
	σ	12.6	25.7	89.7	53.9	15.9	23.2	58.0	59.4	16.8	18.1	68.0	55.2	
	C.V.%	21.2	9.6	21.8	17.5	27.4	8.5	15.3	18.3	28.8	6.7	15.5	15.8	
	Range	36-80	228-324	235-600	220-370	34-88	238-338	320-500	205-355	32-108	242-288	340-585	235-435	
3/11/79 to 3/28/79	N	9	9	9	9	9	9	9	9	9	9	9	9	25 mg/l toxic compound added.
	X	58.4	270.2	433.9	350.6	56.9	278.7	440.6	356.1	50.2	278.7	495.9	415.0	
	σ	11.7	18.7	41.0	43.2	8.4	28.4	37.4	56.8	9.5	20.3	47.5	65.6	
	C.V.%	20.0	6.9	9.4	12.3	14.8	10.2	8.5	15.9	18.8	7.3	9.6	15.8	
	Range	36-72	238-290	355-490	280-405	40-67	238-324	360-495	275-460	40-64	260-304	450-585	345-525	
3/29/79 to 4/23/79	N	12	12	12	12	12	12	12	12	12	12	12	12	50 mg/l toxic
	X	89.8	286.3	416.7	332.9	80.5	287.8	456.7	382.5	65.8	286.2	478.3	401.7	
	σ	7.3	26.9	55.8	60.7	23.8	29.8	60.6	80.1	16.9	35.6	56.4	50.6	
	C.V.%	8.1	9.4	13.4	18.2	29.6	10.4	13.3	20.9	25.6	12.4	11.8	12.6	
	Range	80-100	256-332	300-490	260-450	44-120	224-324	360-535	305-560	36-96	228-340	400-575	315-515	

EPA-287 (Cin.)
(4-76)

studies as can be seen in Figure 62. A semilogarithmic plot of these data indicated that the compound strips in accordance with first order decreasing-rate kinetics. The results shown in Figure 63 indicate that there was no deleterious effect with regard to rates of biological solids production and removal of soluble COD when the dosage was changed from 5 to 25 mg/l in the feed. Similar results were obtained when the dosage was changed from 25 to 50 mg/l.

1,1,2-Trichloroethane

The results shown in Figure 64 indicate that 1,1,2-trichloroethane had little or no effect on the performance of the batch activated sludge system with respect to biomass production and soluble COD. The statistical analyses (see Table 15) also indicate that the compound exerts no effect on the biomass production or the soluble COD in the effluent.

Figure 65 shows that the compound is strippable under the conditions of airflow rate employed in these experimentations. Semilogarithmic plots of these data indicate that the removal was in accordance with first order decreasing-rate kinetics. Figure 66 shows that when the dosage of the test compound was increased from 5 to 25 mg/l in the feed, there was little or no effect on the rate of removal of soluble COD nor the course of biomass production. Similar results were obtained when the dosage was increased from 25 to 50 mg/l in the feed.

Bromoform

Figure 67 shows that bromoform at the concentrations employed in these studies had no effect on the soluble residual COD or the biological solids concentration as compared to values observed in the control system. This observation is substantiated by the results of the statistical analyses which are shown in Table 16.

Although the immiscibility of bromoform and water contributed to the erratic results, Figure 68 shows that the compound was strippable under the conditions of these experimentations. Figure 69 shows that increasing the bromoform concentration in the feed from 5 to 25 mg/l had no effect on the rate of COD removal or of biomass accumulation. Similar results were obtained when the dosage was changed from 0 to 5 mg/l and from 25 to 50 mg/l. There were no large differences in effluent suspended solids concentration in the control and the test units.

Tetrachloroethane

Tetrachloroethane administered at the various dosages employed in these experimentations exhibited no effect on the soluble COD or biomass accumulation in the batch activated sludge system (Figure 70). This observation is verified by the results of the statistical analyses shown in Table 16.

Figure 71 shows that the compound was strippable under the conditions of the present experimentation. The effect on soluble residual COD and

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

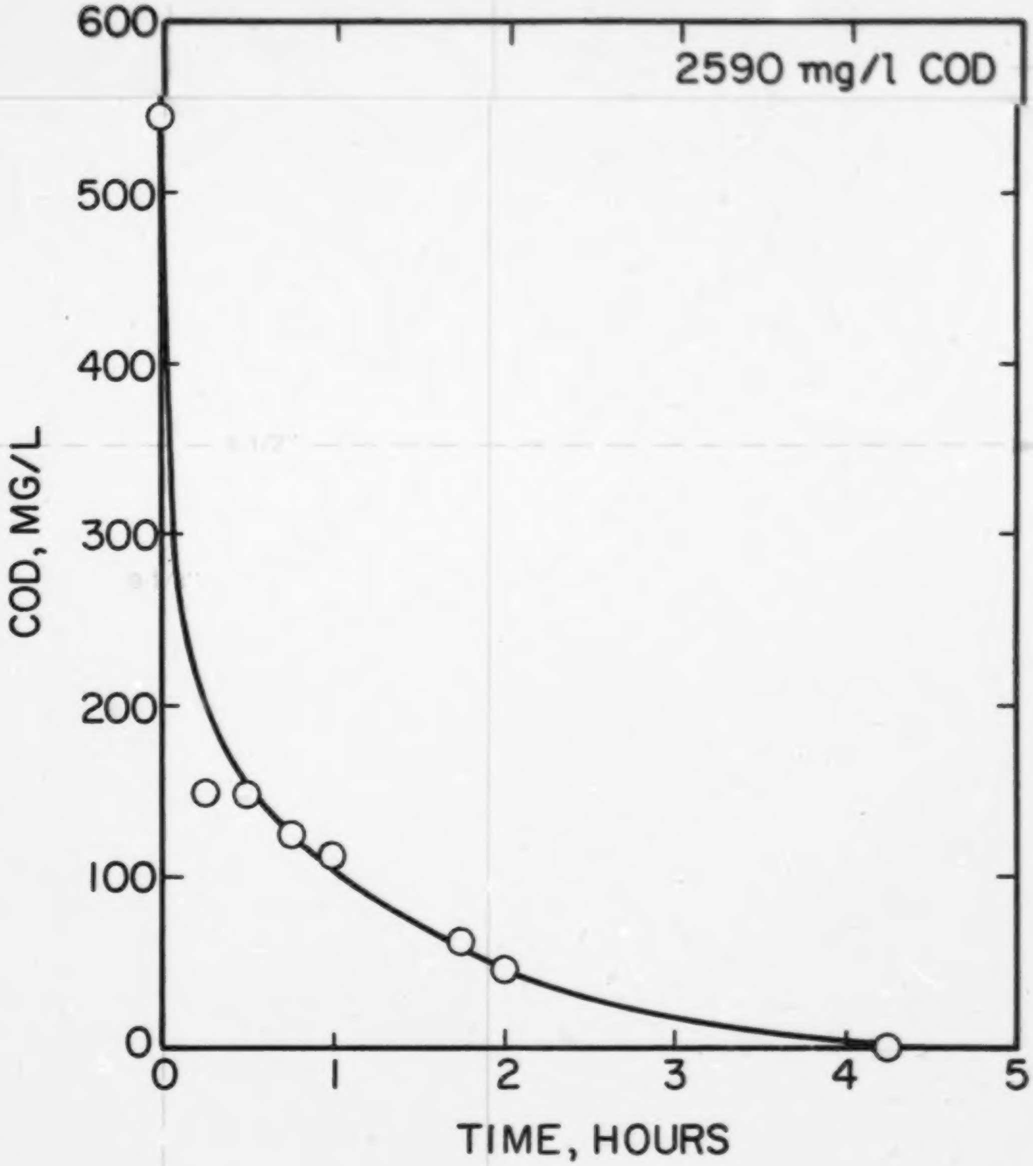

Figure 62. Stripping of 1,2-dichloroethane in batch growth reactor.

BEGIN LAST LINE OF TEXT

3/8"

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

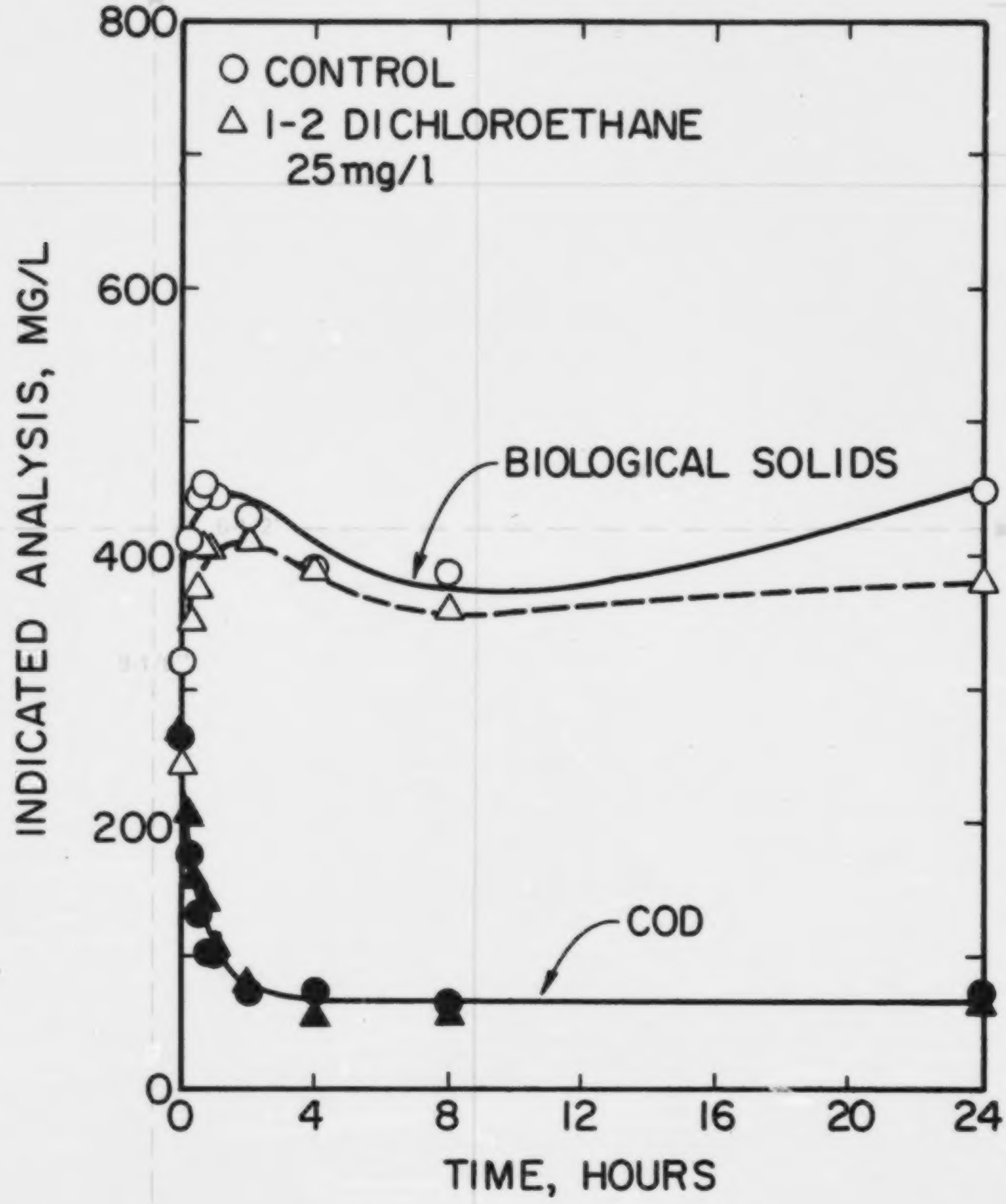

Figure 63. Growth and COD removal of 1,2-dichloroethane unit, dosage=25 mg/l

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

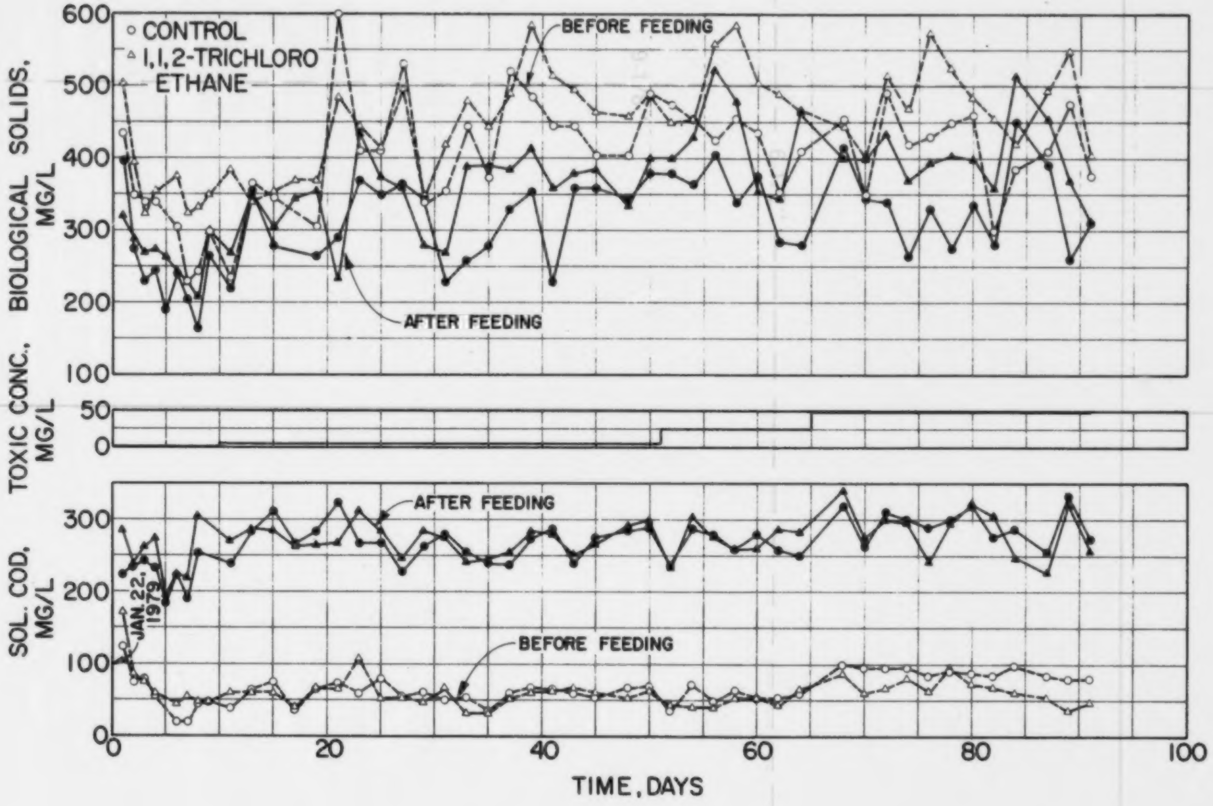

Figure 64. Operational results of batch control and 1,1,2-trichloroethane units.

EPA-267 (Cin.)
(4-76)

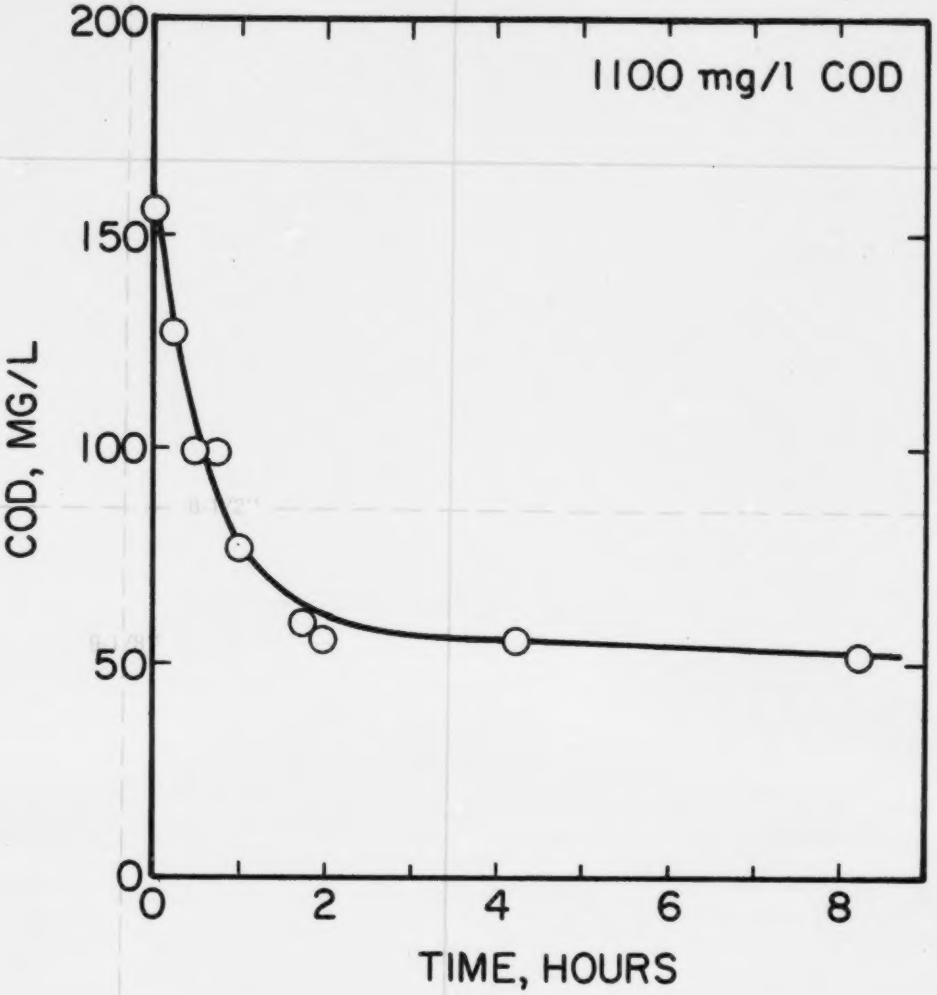

Figure 65. Stripping of 1,1,2-trichloroethane in the batch growth reactor.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

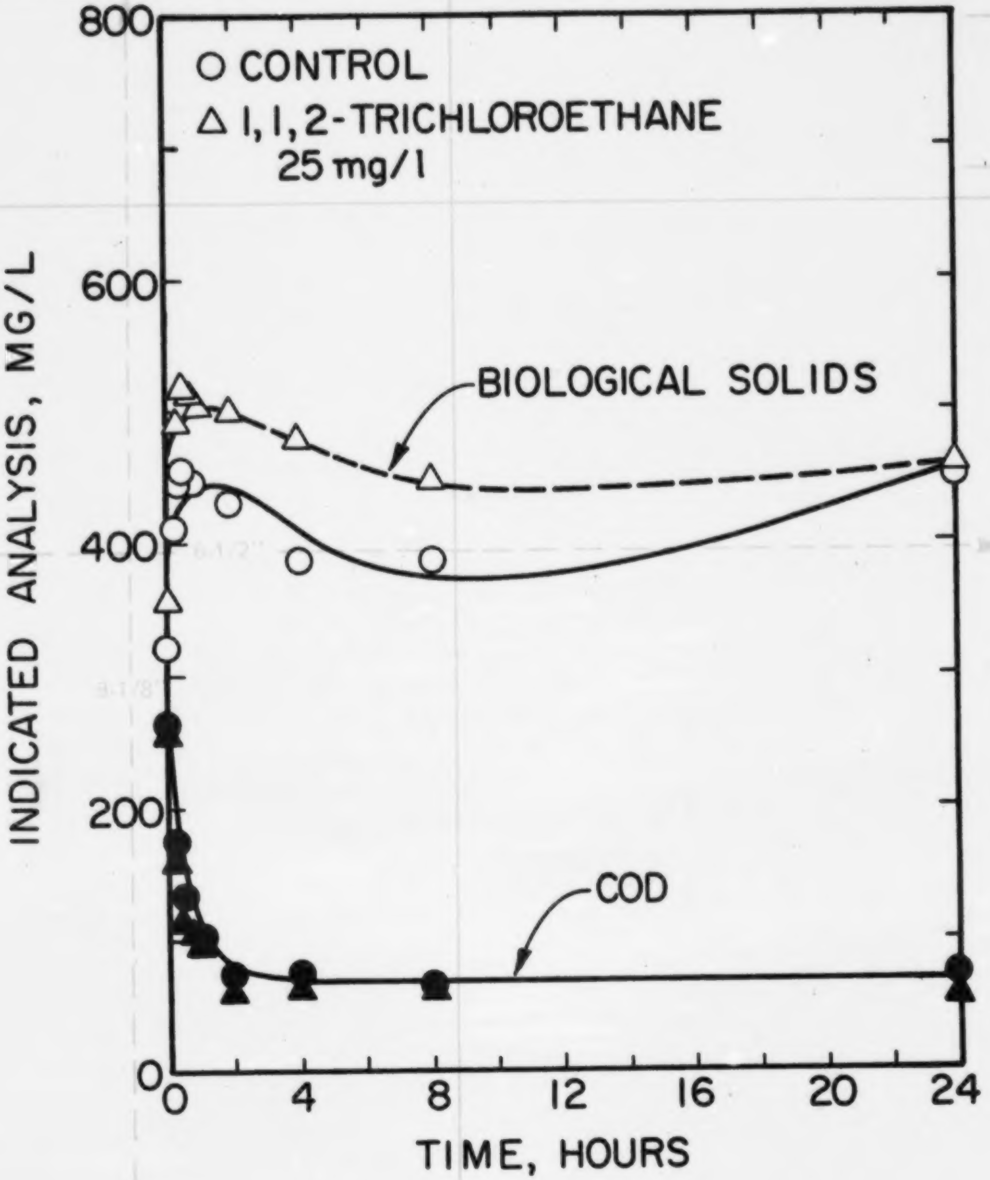

Figure 66. Growth and COD removal of 1,1,2-trichloroethane unit, at 25 mg/l.

EPA-287 (Cin.)
(4-76)

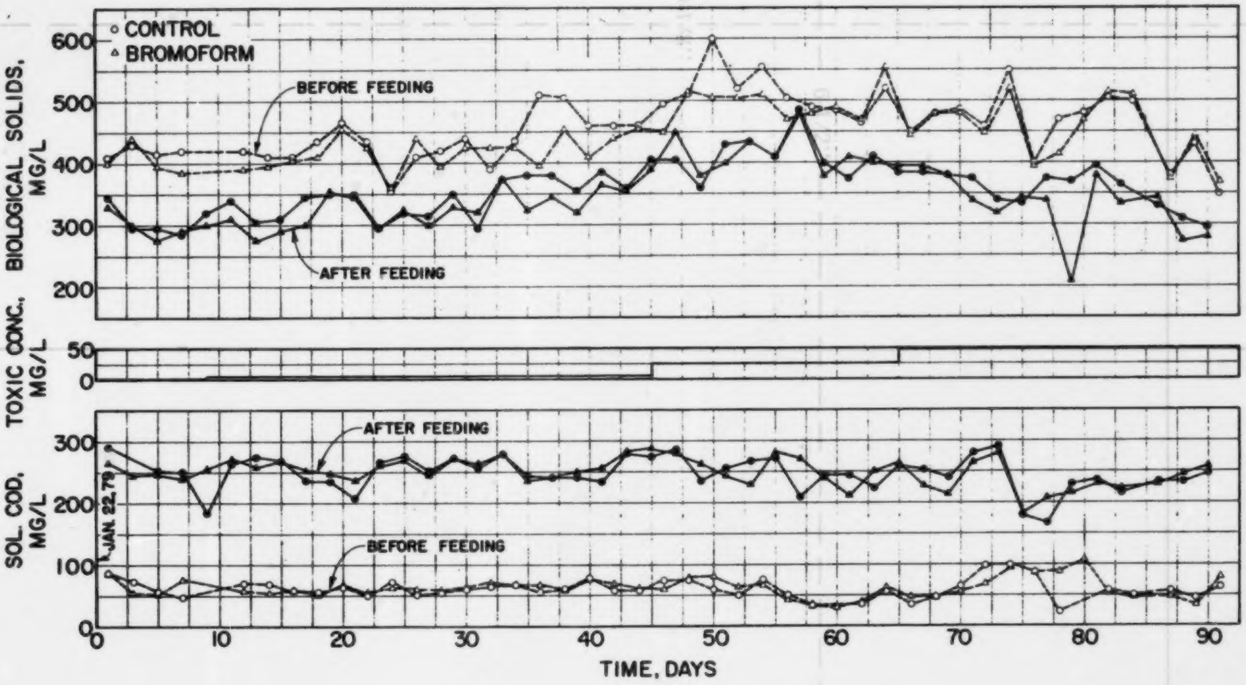

Figure 67. Operational results of batch control and bromoform units.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 16. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR BATCH ACTIVATED SLUDGES DOSED WITH BROMORFORM AND TETRACHLOROETHANE

Date	Parameter	CONTROL				BROMOFORM				TETRACHLOROETHANE				Remarks
		COD		Solids		COD		Solids		COD		Solids		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
1/23/79 to 1/3/79	N	4	4	4	5	4	5	4	5	4	4	4	5	No toxic compound added.
	X	66.0	244.8	418.8	308.0	68.0	250.6	405.0	299.0	53.8	267.0	413.8	313.0	
	σ	16.9	44.2	8.5	24.4	16.9	9.9	24.2	20.1	10.4	21.6	13.8	19.2	
	C.V.%	25.6	18.0	2.0	7.9	24.9	4.0	6.0	6.7	19.4	8.1	3.3	6.2	
	Range	48-86	184-290	410-430	280-345	53-88	240-265	385-440	275-330	249-298	249-298	400-430	290-335	
2/1/79 to 3/8/79	N	17	17	17	17	17	17	17	17	17	17	17	17	5 mg/1 toxic compound added.
	X	62.1	255.1	436.5	341.5	62.8	258.8	411.8	325.3	62.6	257.0	438.2	345.3	
	σ	7.4	20.4	38.8	29.8	6.6	14.6	39.9	28.4	5.6	14.8	43.6	27.6	
	C.V.%	11.9	8.0	8.9	8.7	10.6	5.6	9.7	8.7	8.9	5.8	10.0	8.0	
	Range	52-78	208-280	355-510	295-385	52-76	236-284	360-455	275-375	55-74	228-280	345-520	295-400	
3/9/79 to 3/28/79	N	9	10	10	10	10	10	10	10	10	9	10	10	25 mg/1 toxic compound added.
	X	57.3	256.8	511.8	411.5	56.6	256.3	495.0	413.5	55.2	262.1	497.5	420.0	
	σ	16.0	19.8	41.7	34.2	18.1	24.9	29.7	32.3	11.7	19.3	34.3	19.6	
	C.V.%	28.0	7.7	8.2	8.3	31.9	9.7	6.0	7.8	21.2	7.4	6.9	4.7	
	Range	35-76	224-288	458-600	360-485	31-80	212-288	450-555	380-480	25-72	234-288	445-545	395-455	
3/29/79 to 4/23/79	N	12	13	13	13	13	13	13	13	12	13	13	13	50 mg/1 toxic compound added.
	X	61.2	236.4	456.9	356.9	65.8	235.2	451.5	333.8	66.0	240.9	466.9	359.2	
	σ	23.7	34.6	54.9	31.6	23.0	27.5	51.0	53.2	28.8	35.7	58.8	36.2	
	C.V.%	3.9	14.6	12.0	8.8	35.0	11.7	11.3	15.9	43.6	14.8	12.6	10.1	
	Range	24-99	168-281	350-550	295-395	34-108	184-267	370-520	210-395	40-128	180-296	380-575	295-415	

EPA-287 (Cin.)
(4-76)

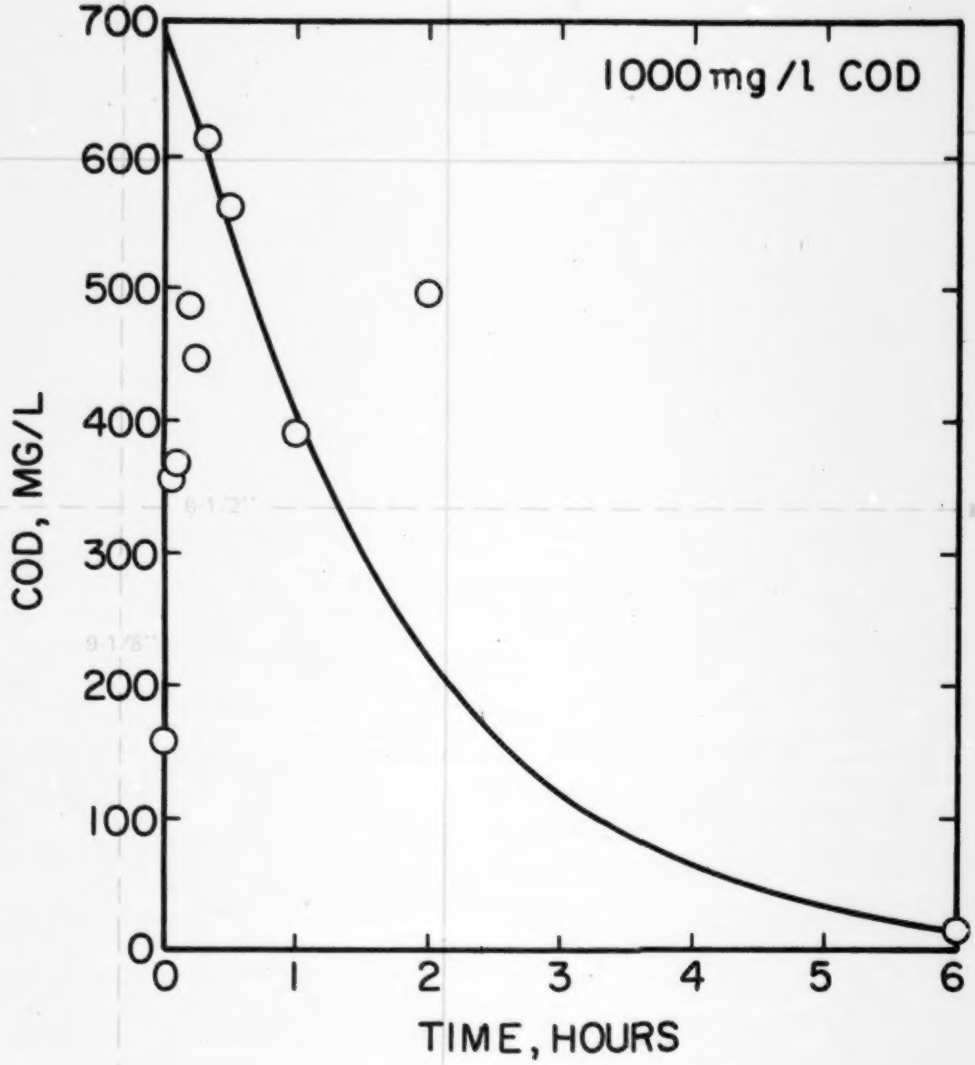

Figure 68. Stripping of bromoform in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

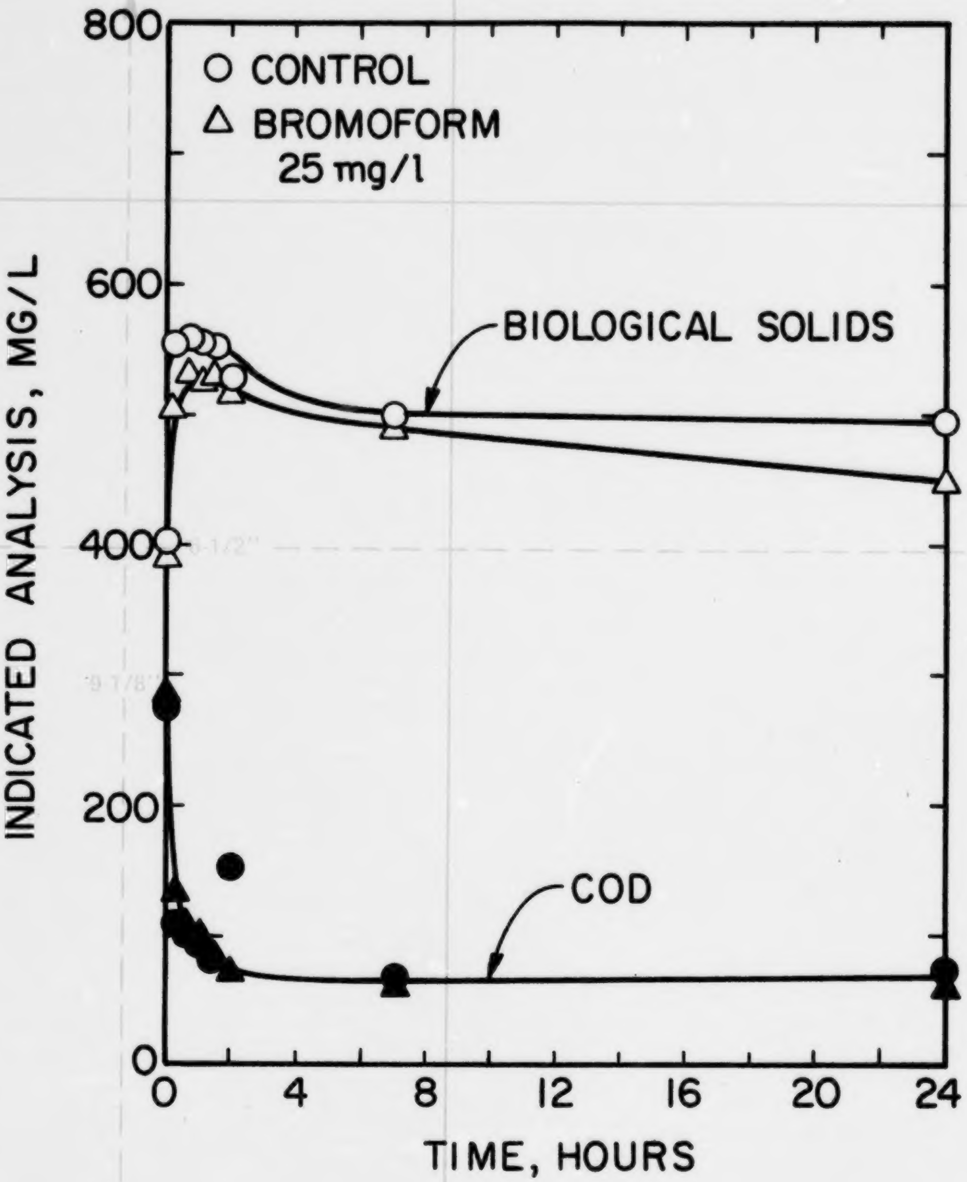

Figure 69. Growth and COD removal of batch bromoform unit, dosage=25 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-267 (Cin.)
(4-76)

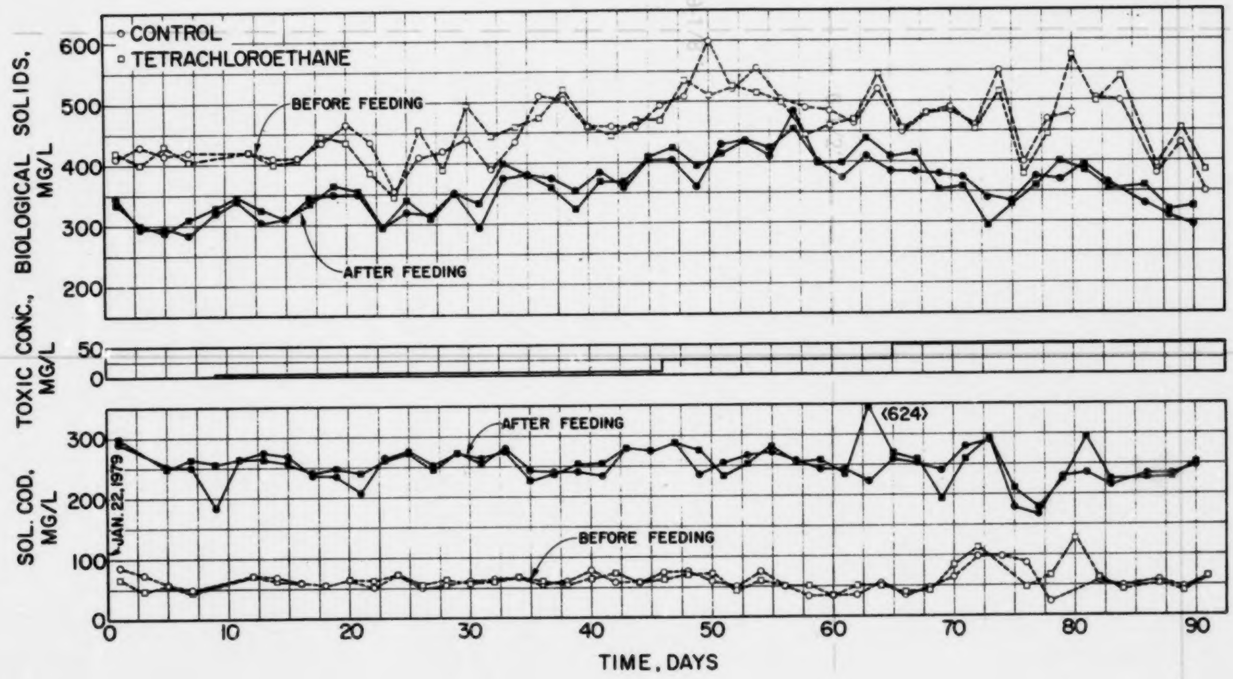

Figure 70. Operational results of batch control and tetrachloroethane units.

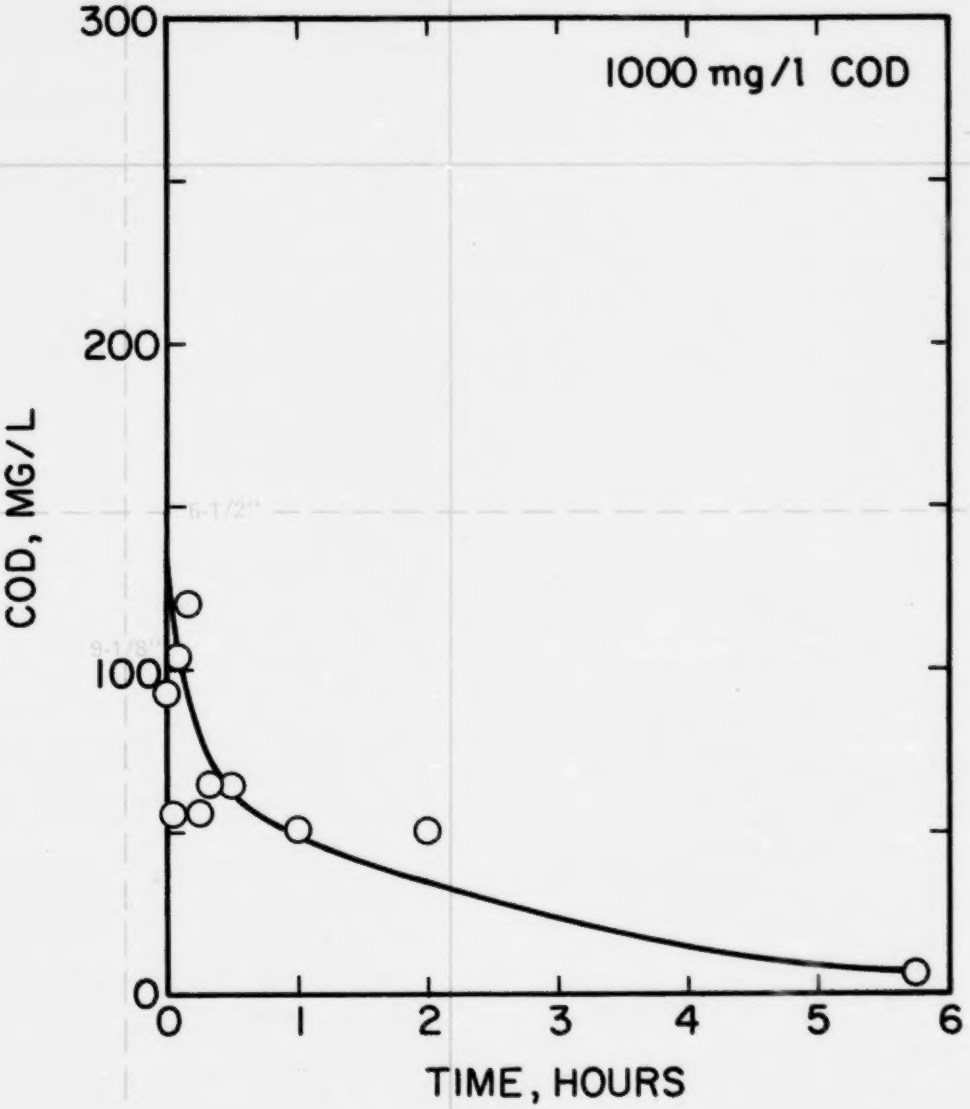

Figure 71. Stripping of tetrachloroethane in the batch growth reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8''
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

biomass accumulation rate when the dosage was changed from 0 to 5 mg/l is shown in Figure 72. It is seen that addition of tetrachloroethane had no effect on the system. Similar results were obtained when the dosage was increased from 5 to 25 mg/l and from 25 to 50 mg/l. The presence of tetrachloroethane in the feed had no effect on the clarity of supernatant during this experimentation.

PHASE II - CONTINUOUS FLOW PILOT PLANT STUDIES

Eight compounds were chosen for study in continuous flow pilot plants operated at $\mu_n = 0.2$ hour^{-1}. Four of these were studied also in extended aeration pilot plants. Thus, for four compounds, results with three different operational modes could be compared, while with four others, results could be compared for a batch system and a fairly high rate continuous flow system.

Control Unit, $\mu_n = 0.2$ days^{-1}

Figure 73 shows the performance of the unit which received the municipal sewage from the Stillwater wastewater treatment plant. The unit did not receive any priority pollutants. The figure shows the performance of the control unit from the beginning of the data-taking period in mid-September through December of 1977. This time period corresponded with the investigation of effects of benzene and phenol which were dosed to similar activated sludge units and also to the investigational period for the dosage of phenol to the extended aeration unit. The variations in feed COD reflect the normal variations in the COD of municipal sewage from Stillwater. Except for a short period in late September (see the 25th day) the soluble COD in the effluent was well below 50 mg/l. The high COD on the 25th day was due to leakage of oil into the line from the feed pump. It is also seen from Figure 73 that the effluent suspended solids concentration was extremely low. In general, it may be concluded that the continuous flow control unit provided exceptionally good results during this study period.

Batch COD removal studies made on October 18 and on November 16, 1977 using inocula from excess pilot plant sludge on those days is shown in Figure 74. It is seen from the figure that the removal of soluble COD by this sludge was not very rapid. It is important to note, however, that the initial biological solids concentration in the batch studies was four to five times less than the biomass concentration in the continuous flow unit.

Benzene, $\mu_n = 0.2$ days^{-1}

Comparison of the results shown in Figure 75 for the performance of the benzene unit with the performance over the corresponding time interval in the control shows that with respect to effluent solids and soluble COD in the effluent, the increasing dosages of benzene in the feed from 5 to 20 to 50 mg/l had little or no effect on the operation of the system. However, the suspended solids concentration in the benzene unit was considerably higher.

EPA-287 (Cin.)
(4-76)

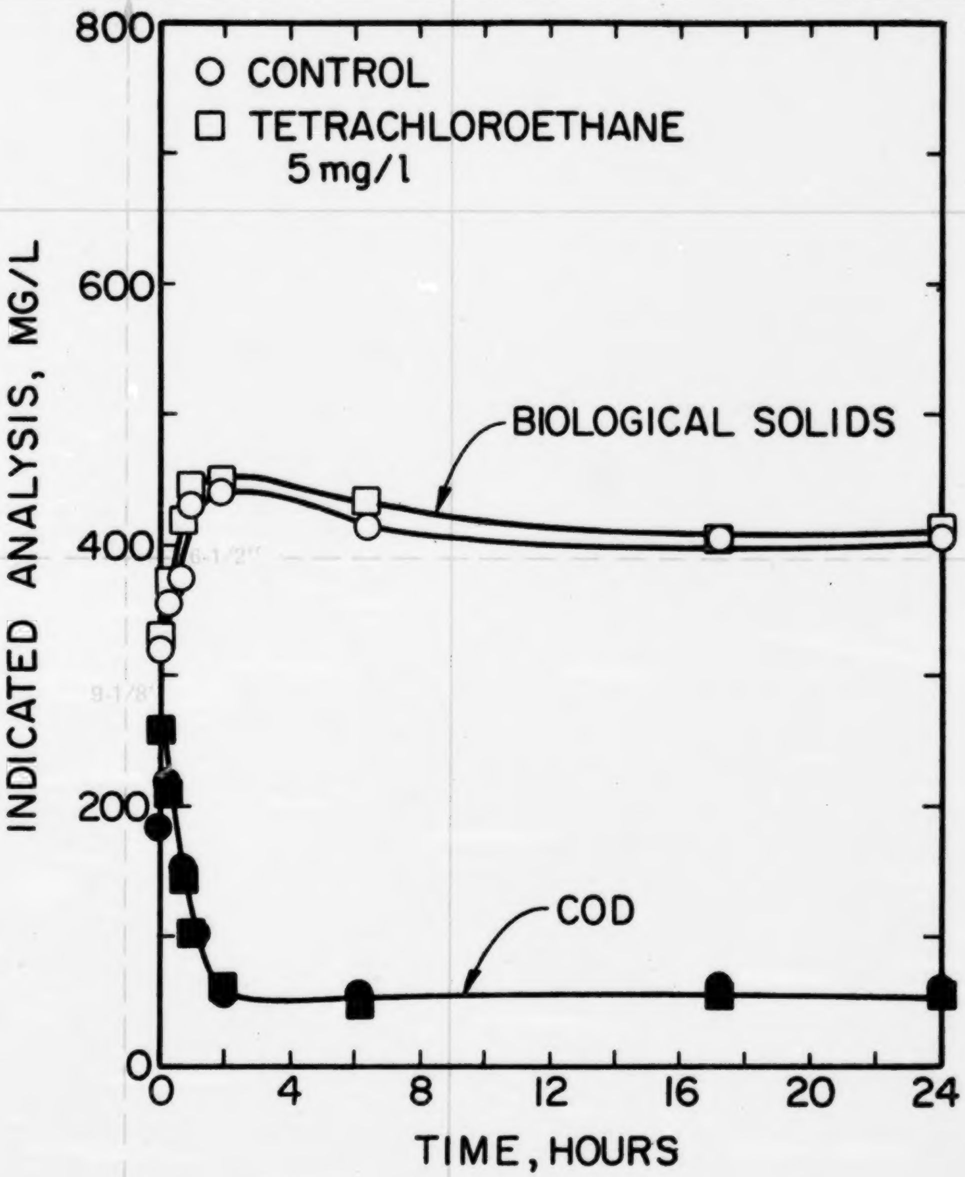

Figure 72. Growth and COD removal of tetrachloroethane unit, dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

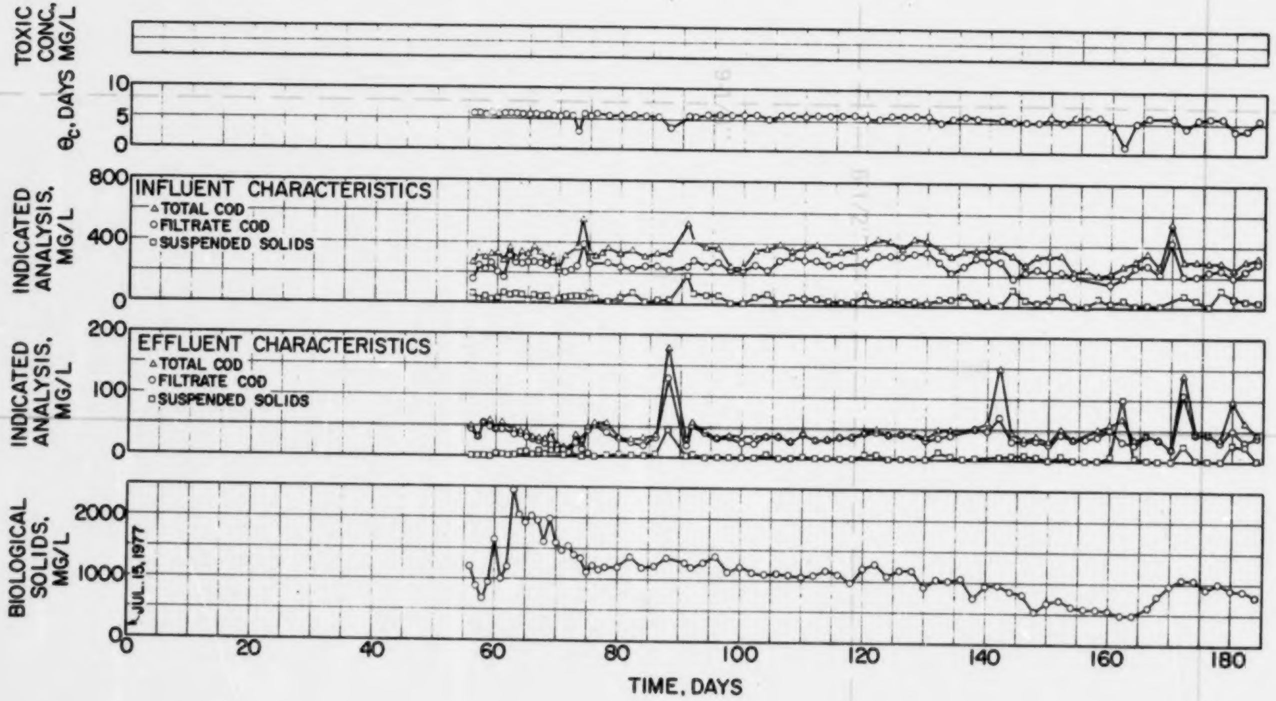

Figure 73. Operational results of continuous flow control (θ_c=5 days), from July 1977.

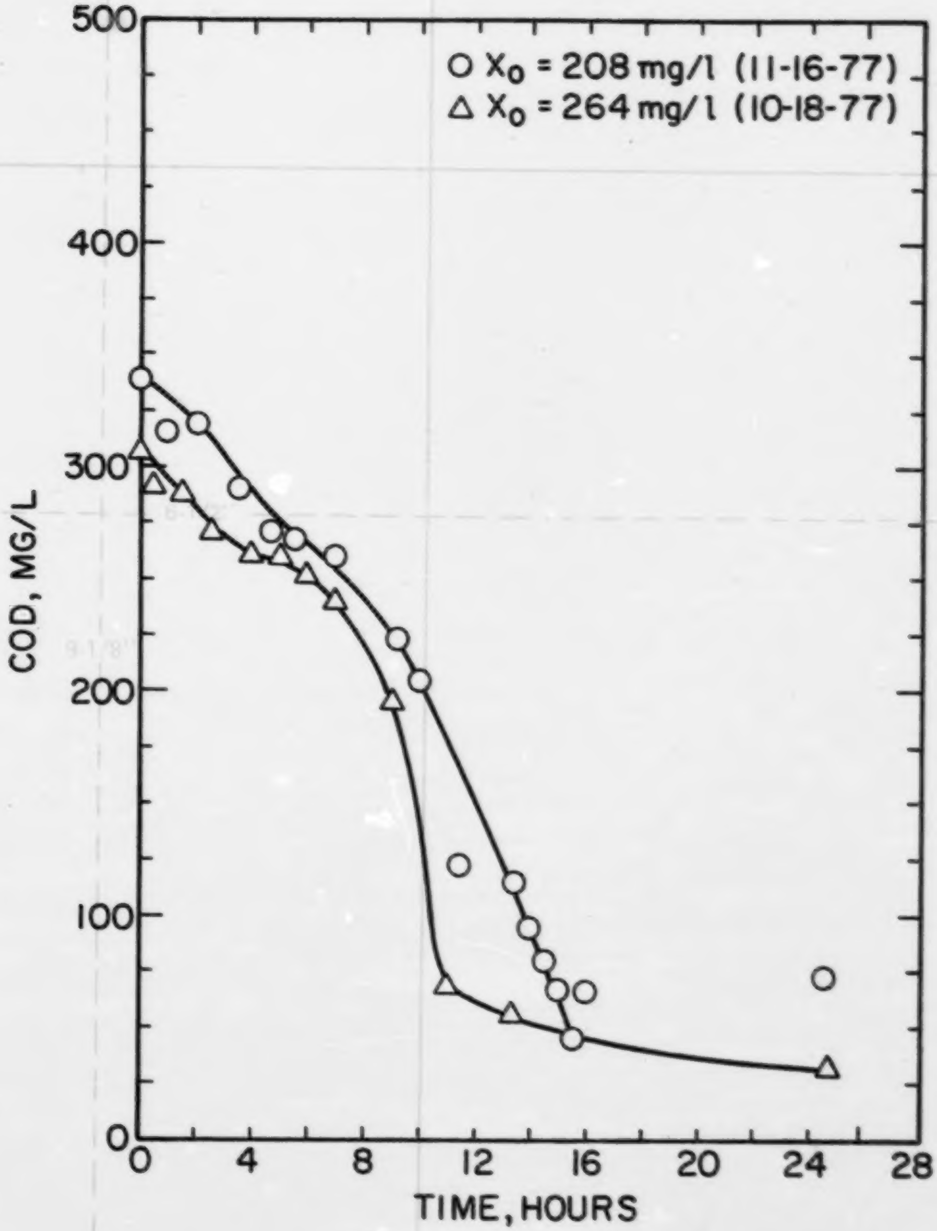

Figure 74. COD removal of control unit.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

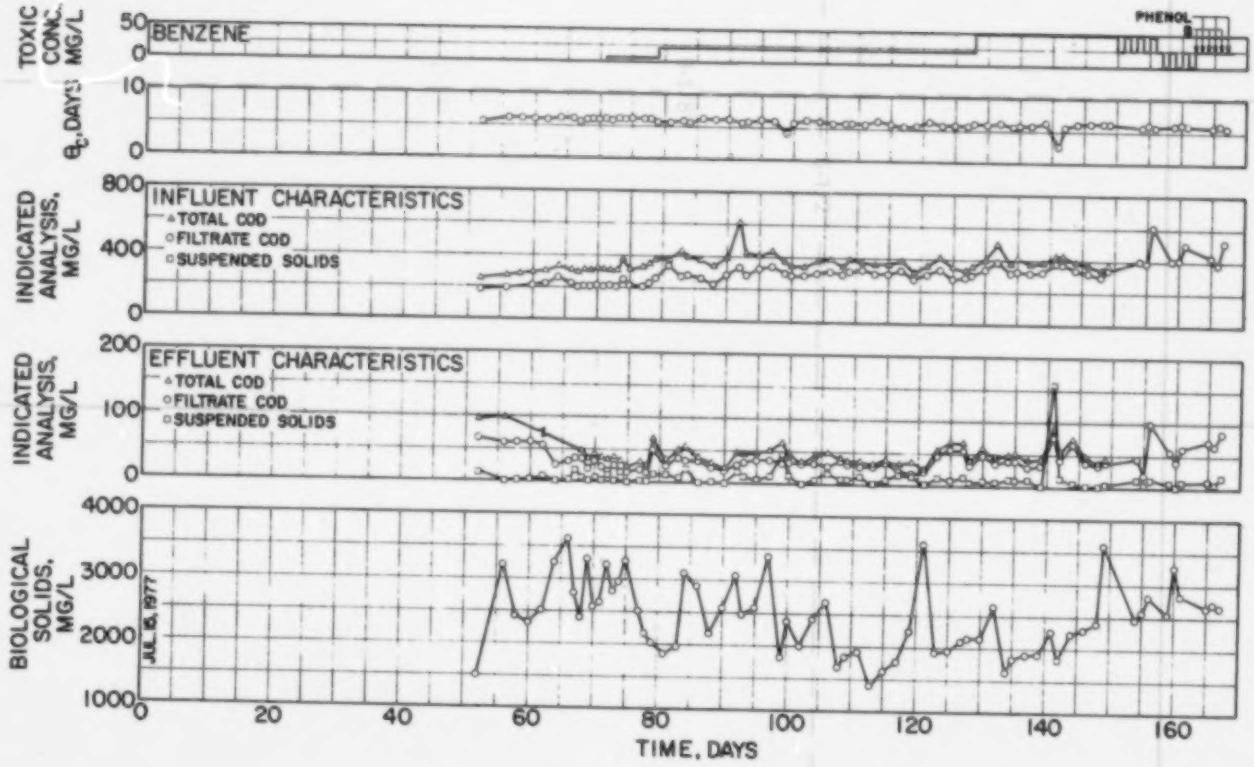

Figure 75. Operational results of continuous flow benzene unit (θ_c=5 days).

than in the control.

Table 17 shows a statistical comparison of pertinent performance characteristics for the control and for the unit which was dosed with varying concentrations of benzene. It is seen that prior to beginning dosage in the benzene unit, the performance of the control unit and of the undosed benzene unit were similar with the exception that biological solids concentration in the benzene unit was nearly twice that in the control. Comparison of effluent characteristics in the control and the benzene-dosed unit (see effluent total COD, filtrate COD and suspended solids) shows that at the dosages of 5 and 20 mg/l of benzene, there were only slight differences in performance. The suspended solids concentration in the unit dosed with 20 or 50 mg/l of benzene was lower than at the 5 mg/l dosage but it was still considerably higher than in the control over a comparable period of time. The difference in effluent suspended solids between the control and the dosed unit was much higher for the benzene dosage of 50 mg/l. However, the suspended solids concentration in the benzene unit even at this high level of dosage remained relatively low, 22 mg/l. From these results it would not appear that benzene at the concentrations employed in these studies caused any stress to the municipal activated sludge treatment plant.

Benzene is rapidly stripped under the conditions of aeration of these experiments as can be seen in Figure 76. Figure 77 shows substrate removal studies made on November 15 and on December 8, 1977 using portions of excess sludge from the activated sludge pilot plant. The experiment run on November 15 employed sludge which was being dosed with 20 mg/l of benzene in the feed and it had been receiving this dosage for over one month. Although the COD removal in the undosed sample was more rapid than in the sample dosed with 20 or 50 mg/l of benzene, the response was reasonably rapid considering the relatively low biological solids concentration. However, for the studies made on December 8, 1977, after the unit had been receiving a dosage of 50 mg/l benzene for approximately two weeks, a reverse situation existed in which the COD was removed faster in the presence of benzene than in the control. However, the COD removal rate in the control system was much lower than it was on November 15. The major point to be emphasized here is that in either event, the addition of up to 80 mg/l of benzene in the feed had relatively minor effects on the course of COD removal.

Phenol, $\mu_n = 0.2$ day^{-1}

Figure 78 shows the performance of an activated sludge unit dosed with varying concentrations of phenol. Comparison of these results with those for the control during the same period, shown in Figure 73, leave little doubt that the presence of phenol in the incoming feed at concentrations of 20 and 50 mg/l caused generally higher soluble COD in the effluent and very noticeably higher concentrations of suspended solids in the effluent. The comparative statistical analyses shown in Table 18 indicate that the average suspended solids concentration in the unit which was to be dosed with phenol ran somewhat higher than in the control in the pre-dosage period. The average soluble COD in the effluent of both units was approximately the same.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 17. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH BENZENE

Date	Parameter	CONTROL							BENZENE							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
9/7/77 to 9/24/77	N	16	17	16	17	16	15	17	0	12	10	11	5	12	12	No toxic compound added.
	X	43.1	310.0	240.2	1494.6	38.6	33.7	4.1	-	301.7	216.7	2822.8	52.6	42.1	5.5	
	σ	16.4	35.7	40.6	535.7	12.7	12.2	3.6	-	17.2	18.0	433.3	25.8	16.2	4.6	
	C.V.%	38.2	11.5	16.9	35.8	32.8	36.1	85.6	-	6.0	8.0	16.0	49.0	39.0	84.0	
	Range	16 - 68	232 - 376	160 - 310	685 - 2448	16 - 58	12 - 56	0 - 10	-	272 - 333	198 - 262	2428 - 3612	36 - 98	20 - 62	2 - 18	
9/25/77 to 10/2/77	N	6	7	5	7	6	6	5	0	7	7	7	7	7	7	5 mg/l toxic compound added.
	X	42.0	357.3	276.0	1357.7	37.3	30.7	3.0	-	338.3	229.0	2709.7	36.4	22.6	5.1	
	σ	18.0	94.7	65.2	313.7	19.5	17.1	3.3	-	29.5	21.1	490.5	14.8	12.7	5.0	
	C.V.%	42.9	26.5	23.6	23.1	52.4	55.7	108.7	-	8.7	9.2	18.1	40.7	56.4	97.5	
	Range	12 - 64	240 - 549	220 - 388	1136 - 2036	12 - 56	12 - 52	0 - 7.5	-	309 - 376	206 - 262	2032 - 3280	24 - 68	15 - 50	0 - 12	
10/3/77 to 11/24/77	N	27	27	26	27	27	26	27	0	29	29	29	29	29	29	20 mg/l toxic compound added.
	X	44.3	369.0	274.6	1170.4	42.8	37.3	3.9	-	389.9	306.8	2330.1	44.1	33.1	10.2	
	σ	34.8	57.0	38.9	108.8	27.8	20.4	8.9	-	56.4	30.5	604.5	11.6	9.8	8.9	
	C.V.%	78.6	15.4	14.2	9.3	65.0	54.6	227.2	-	14.5	9.9	25.9	26.2	29.5	87.0	
	Range	8 - 184	246 - 528	222 - 356	956 - 1360	28 - 178	20 - 130	0 - 45	-	321 - 614	232 - 386	1472 - 3596	18 - 67	18 - 60	0 - 46	
11/25/77 to 12/12/77	N	9	9	9	9	8	8	8	0	10	10	10	10	10	10	50 mg/l toxic compound added.
	X	44.0	340.9	250.8	843.1	57.4	41.1	4.1	-	391.2	338.7	2193.0	53.5	44.3	22.0	
	σ	31.9	31.1	43.9	169.8	38.3	14.6	3.0	-	27.0	25.7	554.5	16.3	15.3	48.0	
	C.V.%	72.4	9.1	17.5	20.1	66.7	35.6	74.2	-	6.9	7.6	25.3	30.5	34.5	218.4	
	Range	4 - 112	274 - 370	181 - 316	520 - 1052	31 - 149	31 - 149	0 - 7.5	-	348 - 434	304 - 386	1636 - 3604	38 - 90	30 - 78	2 - 158	
12/13/77 to 12/24/77	N	6	6	5	6	6	5	6	0	0	6	6	0	6	6	Cyclic changes.
	X	37.3	251.3	172.6	587.0	49.0	41.4	19.2	-	-	457.0	2752.3	-	54.2	8.2	
	σ	28.1	48.0	56.1	71.8	11.8	6.1	39.7	-	-	87.6	296.3	-	27.1	4.2	
	C.V.%	75.4	19.1	32.5	12.2	24.1	14.6	207.0	-	-	19.2	10.8	-	50.0	50.8	
	Range	8 - 76	206 - 338	87 - 232	496 - 712	35 - 63	35 - 51	0 - 100	- -	 -	397 - 615	2462 - 3272	- -	20 - 101	2 - 13	
12/25/77 to 12/31/77	N	2	2	2	2	2	2	2	0	0	3	3	0	3	3	Switching of toxic compounds.
	X	18.0	327.0	267.0	544.5	39.0	35.0	2.5	-	-	446.0	2673.7	-	74.7	11.3	
	σ	2.8	36.8	8.5	89.8	5.7	11.3	3.5	-	-	67.1	33.6	-	9.6	5.0	
	C.V.%	15.7	11.2	31.8	16.5	14.6	32.3	140.0	-	-	15.0	1.3	-	12.8	44.5	
	Range	16 - 20	301 - 353	261 - 273	481 - 608	35 - 43	27 - 43	0 - 5	- -	- -	389 - 520	2660 - 2712	- -	66 - 73	6 - 16	

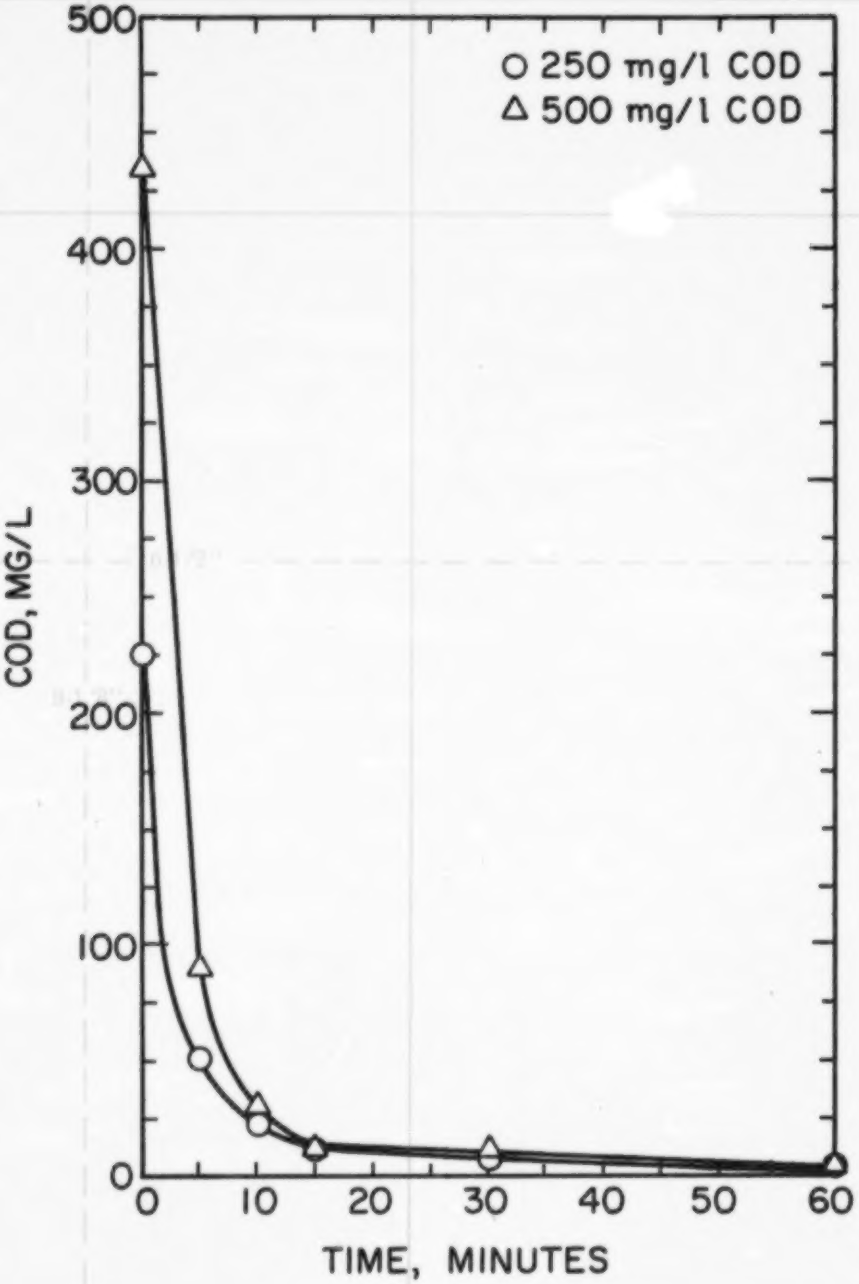

Figure 76. Batch stripping study of benzene in a continuous flow reactor.

EPA-287 (Cin.)
(4-76)

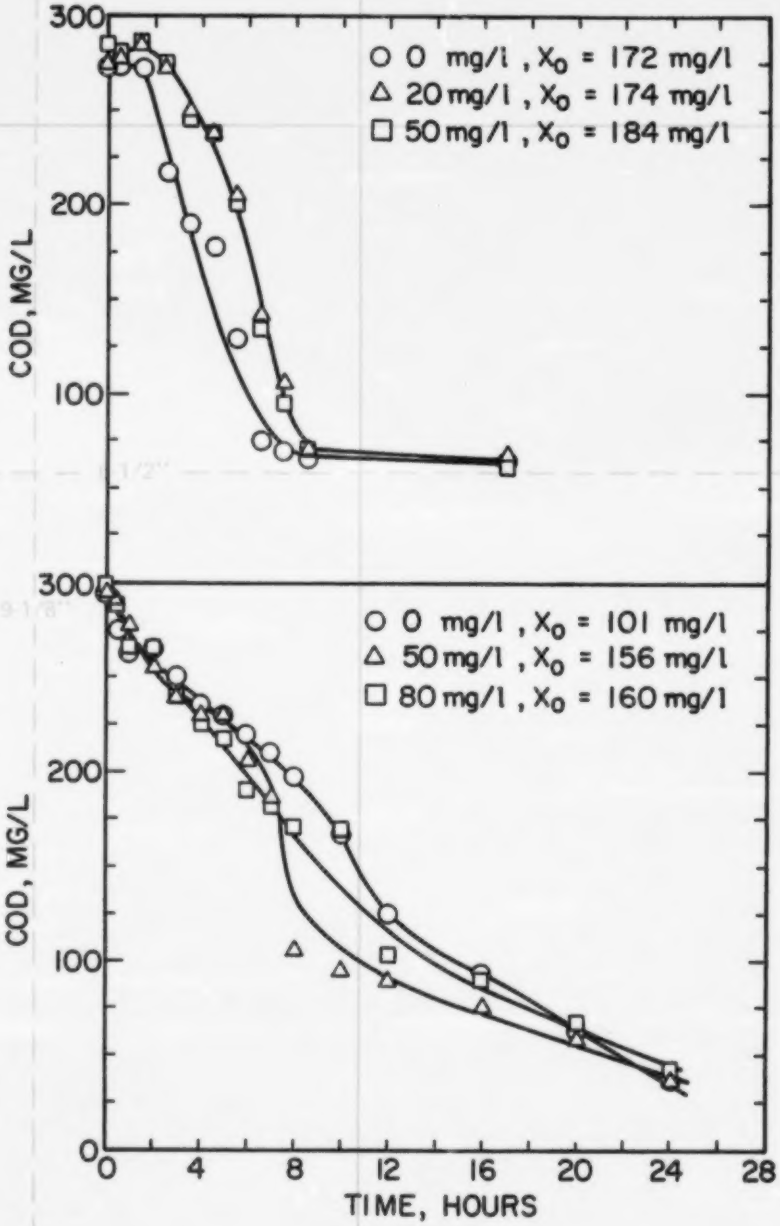

Figure 77. COD removal of continuous flow benzene unit (θ_c=5 days) dosage=20 mg/l (top), dosage=50 mg/l (bottom)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

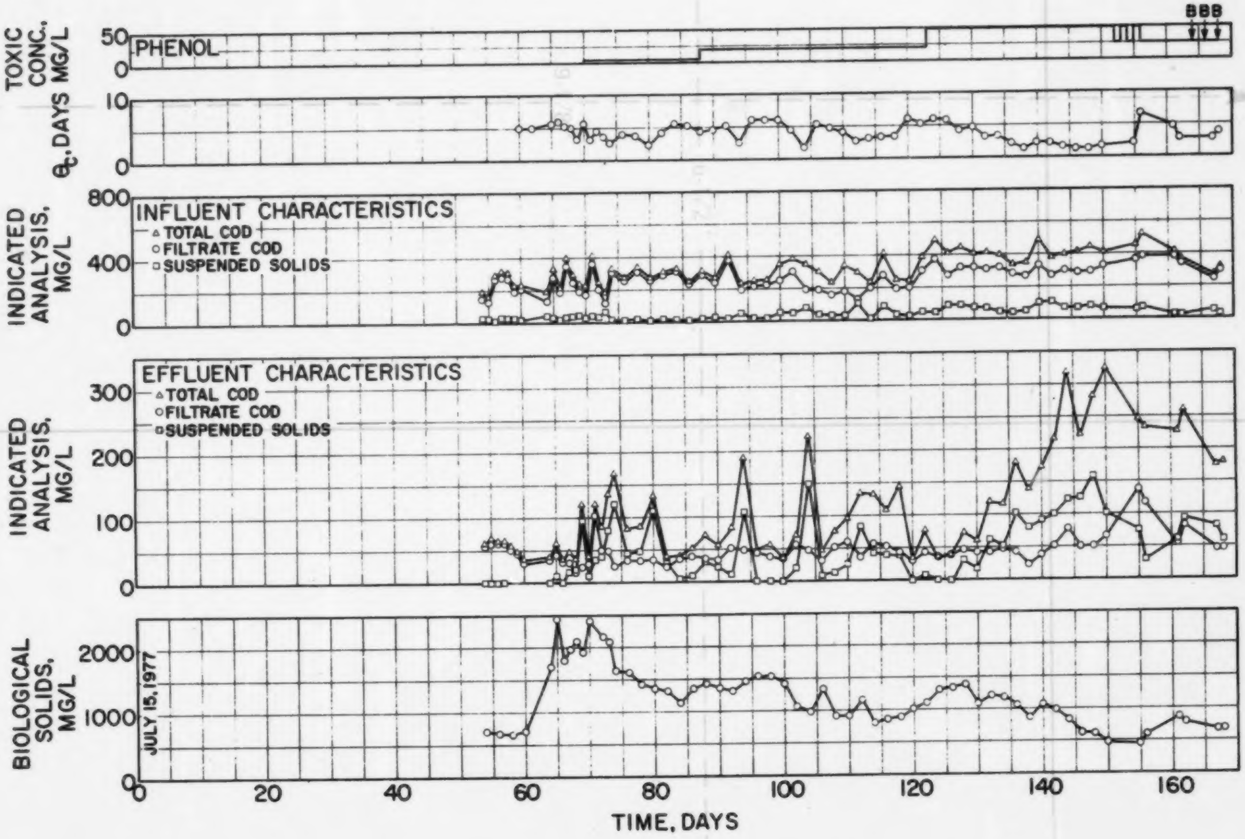

Figure 78. Operational results of continuous flow phenol unit (θ_c=5 days).

EPA-287 (Cin.)
(4-76)

TABLE 18. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH PHENOL

Date	Parameter	CONTROL							PHENOL							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
9/17/77 to 9/23/77	N	7	7	7	7	7	6	7	7	7	7	7	7	7	7	No toxic compound added.
	X	38.9	313.7	255.6	1884.6	32.6	26.3	7.4	35.0	271.0	225.7	2053.6	54.3	30.3	21.6	
	σ	16.4	44.7	23.3	193.0	8.8	7.0	3.0	8.0	72.8	72.5	286.5	30.2	8.8	33.2	
	C.V.%	42.3	14.2	9.1	10.2	26.9	26.5	41.2	22.8	26.8	32.1	14.0	55.6	29.3	153.7	
	Range	24 - 68	268 - 364	212 - 271	1592 - 2056	16 - 40	18 - 36	2.5- 10	20 - 44	192 - 396	136 - 350	1705 - 2445	36 - 120	16 - 36	0 - 95	
9/24/77 to 10/11/77	N	12	13	11	13	12	12	11	11	11	11	11	11	11	11	5 mg/1 toxic compound added.
	X	42.0	344.0	252.7	1333.7	45.5	35.8	7.0	24.9	298.0	269.7	1650.5	92.5	42.2	59.3	
	σ	19.3	69.1	48.1	236.0	44.2	32.4	12 8	15.9	60.3	66.8	455.2	42.5	22.0	44.9	
	C.V.%	45.9	20.1	19.0	17.7	97.2	90.4	182.7	63.7	20.2	24.8	27.6	45.9	52.2	75.9	
	Range	12 - 76	240 - 549	208 - 388	1136 - 2036	12 - 178	12 - 130	0 - 45	10 - 65	185 - 412	119 - 368	1140 - 2635	39 - 169	24 - 104	5 - 135	
10/12/77 to 11/15/77	N	17	17	16	17	17	16	17	17	17	17	17	17	17	17	20 mg/1 toxic compound added.
	X	40.0	370.1	269.8	1163.5	37.8	34.2	1.9	44.2	306.8	227.6	1154.7	92.2	45.2	33.8	
	σ	41.7	63.8	31.1	100.0	7.2	8.1	3.0	25.5	66.8	60.9	252.2	57.9	9.2	42.3	
	C.V.%	86.9	17.2	11.5	8.6	19.1	23.6	158.0	57.7	21.8	26.8	21.8	62.9	20.4	125.0	
	Range	8 - 184	246 - 528	222 - 324	972 - 1360	28 - 57	20 - 53	0 - 7.5	13 - 105	232 - 416	137 - 380	803 - 1542	34 - 224	32 - 60	0 - 150	
11/16/77 to 12/13/77	N	14	14	14	14	13	13	13	14	14	14	14	14	14	14	50 mg/1 toxic compound added.
	X	40.3	363.4	277.8	933.1	51.3	39.8	3.5	71.6	415.5	306.1	1002.1	164.6	47.0	74.6	
	σ	26.1	44.4	52.9	191.4	30.4	11.5	4.0	20.4	43.8	29.2	282.7	98.5	13.2	49.3	
	C.V.%	64.8	12.2	19.0	20.5	59.3	28.9	114.9	28.5	10.5	9.5	28.2	59.9	28.0	66.0	
	Range	4 - 112	274 - 440	181 - 356	520 - 1196	31 - 149	27 - 70	0 - 12.5	40 - 106	340 - 492	264 - 372	485 - 1385	36 - 325	23 - 78	0 - 159	
12/14/77 to 12/25/77	N	7	7	6	7	7	6	7	4	4	4	4	4	4	4	Cyclic changes.
	X	34.3	258.4	187.3	571.9	47.0	39.0	17.2	43.2	438.0	366.0	675.8	242.0	99.0	64.8	
	σ	26.9	47.6	61.8	76.8	12.0	8.0	36.7	25.5	66.8	19.8	183.2	14.1	37.4	26.6	
	C.V.%	78.5	18.4	33.0	13.4	25.5	20.5	213.2	59.0	15.2	5.4	27.1	5.8	37.8	41.1	
	Range	8 - 76	206 - 338	87 - 261	481 - 712	35 - 63	27 - 51	0 - 100	20 - 70	362 - 520	340 - 382	455 - 858	228 - 260	55 - 139	30 - 93	
12/26/77 to 12.31/77	N	1	1	1	1	1	1	1	2	2	2	2	2	2	2	Switching of toxic compounds.
	X	20	353	273	608	43	43	0	37.5	287.5	272.5	681.0	178.0	47	70.5	
	σ	-	-	-	-	-	-	-	17.7	36.1	38.9	5.7	2.8	0	14.8	
	C.V.%	-	-	-	-	-	-	-	47.1	12.5	14.3	0.8	1.6	0	21.1	
	Range	-	-	-	-	-	-	-	25 - 50	262 - 313	245 - 300	677 - 685	176 - 180	47 - 47	60 - 81	

EPA-287 (Cin.)
(4-76)

At a dosage of 5 mg/l of phenol, the average suspended solids in the effluent during the period September 24 to October 11, 1977 was 59 mg/l whereas in the control it was 7 mg/l. There was only a slight difference in the amount of soluble COD in the effluent and the large difference in total COD (92.5 vs. 45.5) was due essentially to the suspended solids concentration. During the period of dosage of 20 mg/l, the total effluent COD did not increase above that observed when the dosage was 5 mg/l and again the major difference between the quality of the control effluent as compared to that of the dosed unit was the higher suspended solids in the unit dosed with phenol. An increase in dosage to 50 mg/l led to extremely high levels of suspended solids in the effluent, whereas those in the effluent of the control unit remained very low. The microscopic appearance of the sludge in the control unit was considerably different from that in the unit which was subjected to dosage with phenol. The major difference was the highly filamentous nature of the sludge in the phenol unit. It is also important to note in Figure 78 that shock loadings of phenol administered near the end of the experimental period caused considerable leakage of soluble COD in the effluent.

It was determined (Figure 79) that phenol was not strippable under the conditions of these experiments. Figure 80 shows the results of a batch study made using excess sludge from the pilot plant; the unit had been receiving a dosage of 20 mg/l phenol for approximately one month when the experiment was conducted. It is seen that the increasing dosage of phenol caused some retardation of COD removal. The difference between the response for the 0 dosage and the 20 mg/l dosage, to which the sludge was acclimated, is rather small compared to the response when the initial concentration of phenol was 50 mg/l. A second study of COD removal rates was conducted using sludge from the unit when the feed concentration of phenol has been 50 mg/l for 17 days (Figure 81). The COD was removed more rapidly in the presence of 50 or 100 mg/l phenol than in the absence of phenol, indicating a possible adverse effect of the absence of phenol after long acclimation to its presence.

Phenol, Extended Aeration

The general impression received when one compares results shown in Figure 82 for an extended aeration plant receiving varying dosages of phenol with results for faster growing activated sludge (shown in Figure 78) is that the extended aeration pilot plant gave somewhat better results with respect to suspended solids concentration in the effluent. However, it is clear that the presence of phenol did cause some deterioration in effluent quality. A separate control could not be run for the extended aeration unit but, using the pre-dosage period as an indication of the overall performance in the absence of phenol, it can be seen from the graph that the addition of even 5 mg/l phenol in the feed caused an increase in soluble COD and a rise in suspended solids in the effluent. However, after the unit had acclimated to this concentration of phenol, an increase from 5 to 20 mg/l did not appear to affect the concentration of soluble COD in the effluent although there was a short-lived rising trend in the effluent suspended solids concentration. An increase to 50 mg/l caused a rising tendency in soluble COD and some increase in effluent suspended solids concentration. When the unit was subjected to

TYPING GUIDE SHEET
BEGIN FIRST-LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/8"

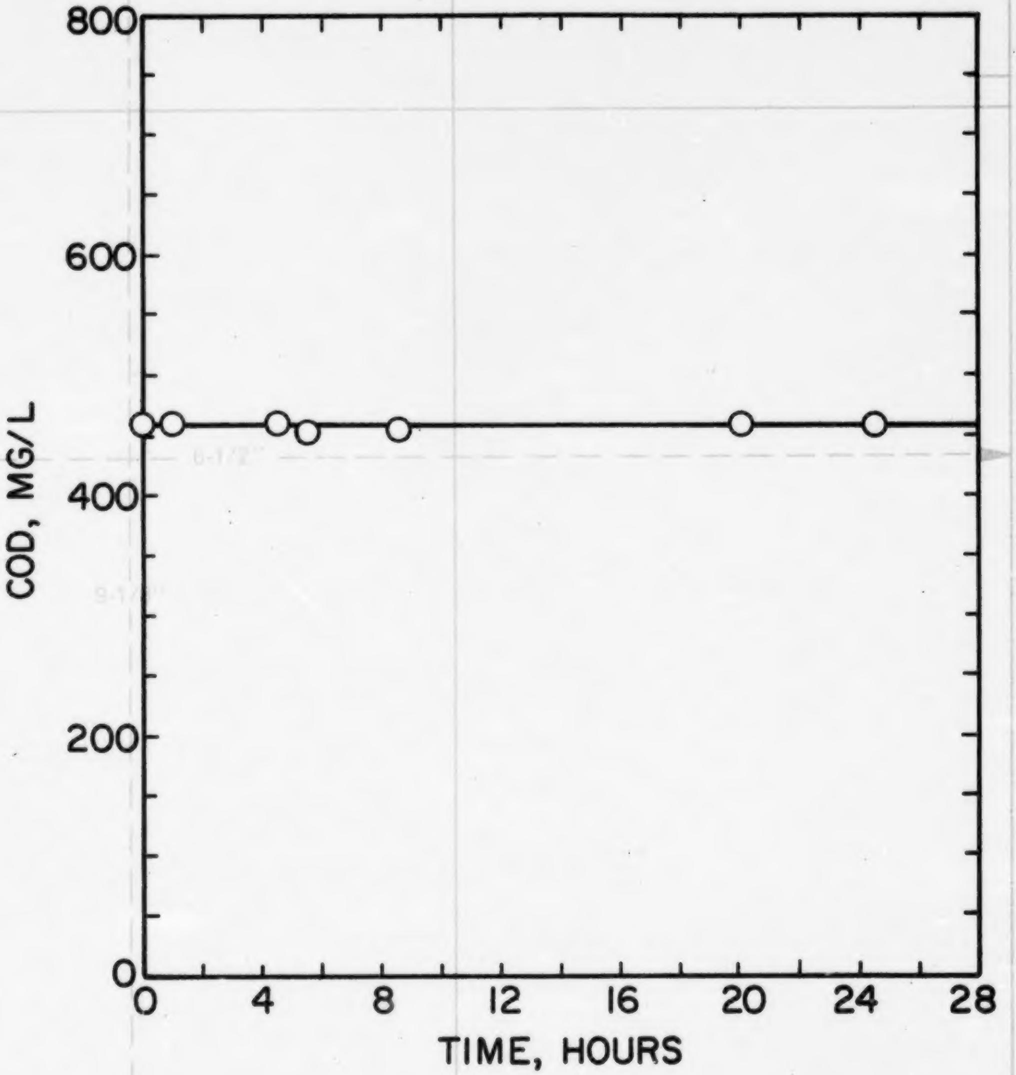

Figure 79. Batch stripping study of phenol in a continuous flow reactor.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

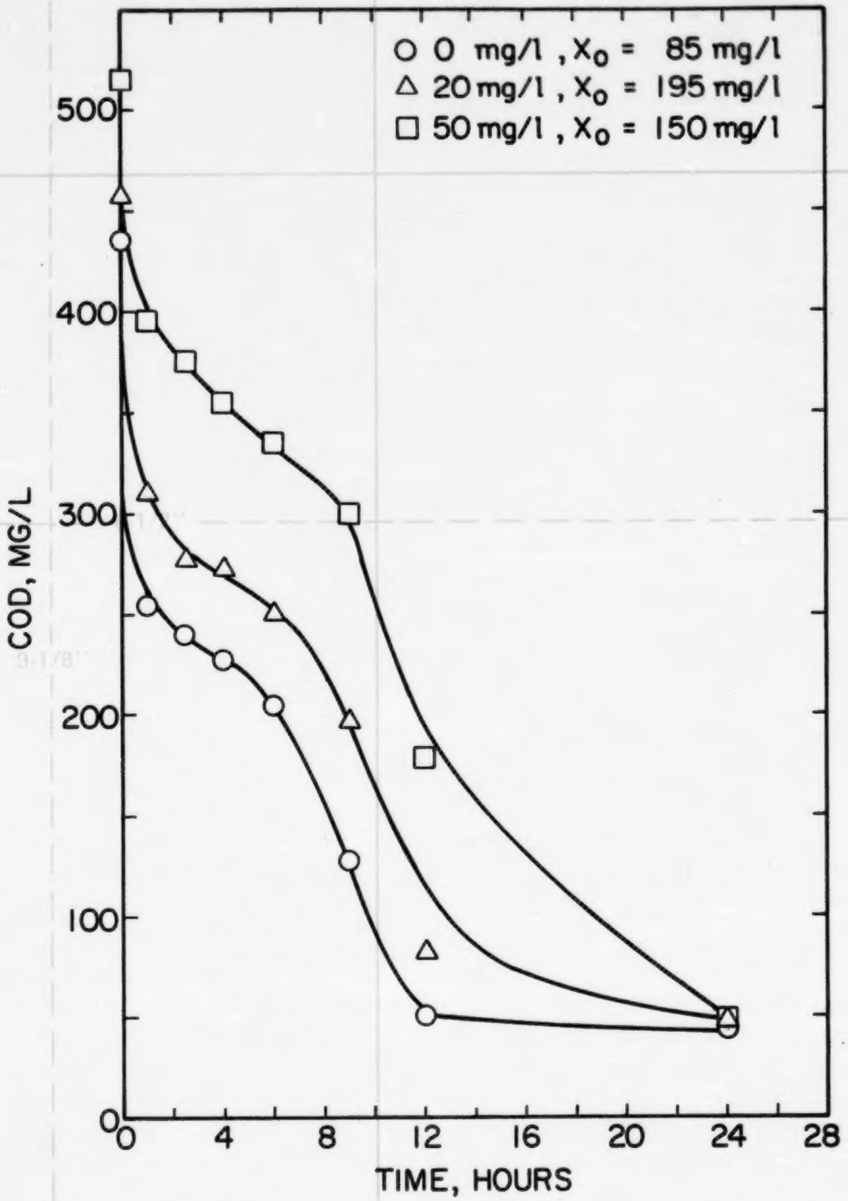

Figure 80. COD removal of continuous flow phenol unit (Θ_c=5 days) dosage=20 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

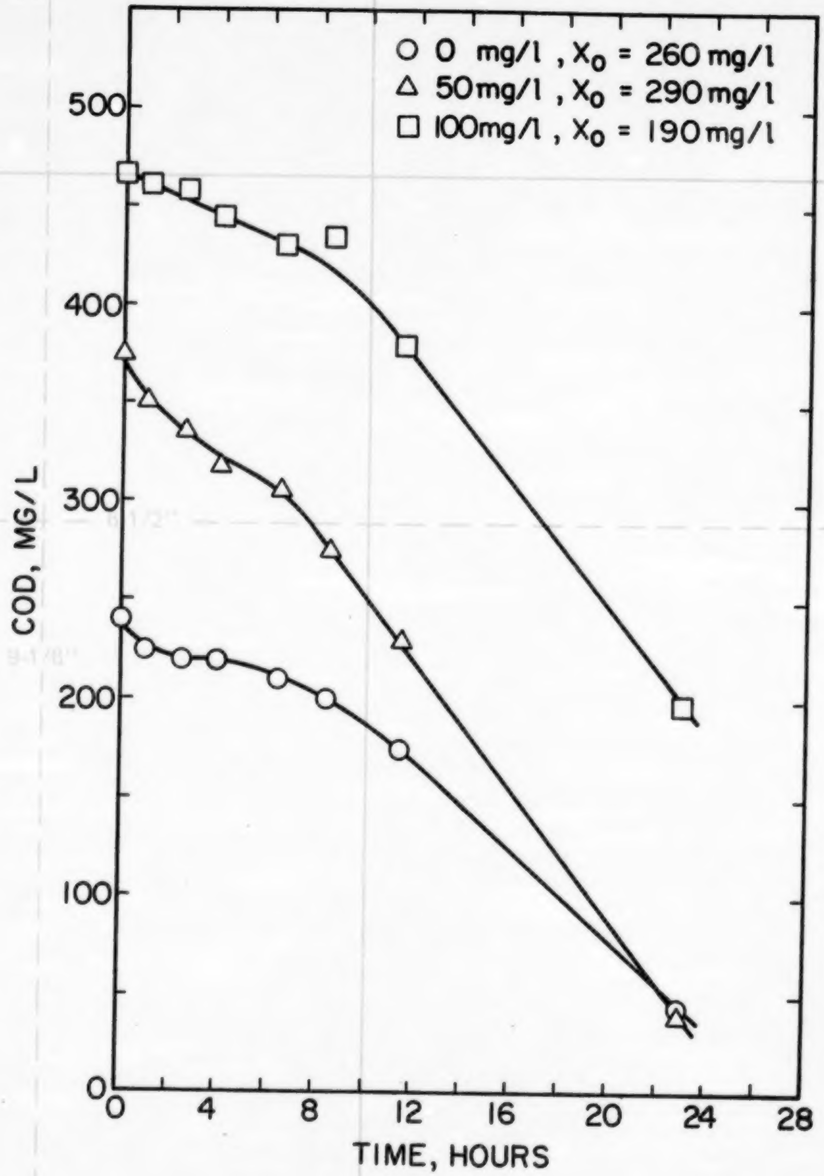

Figure 81. COD removal of continuous flow phenol unit (θ_c = 5 days) dosage=50 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

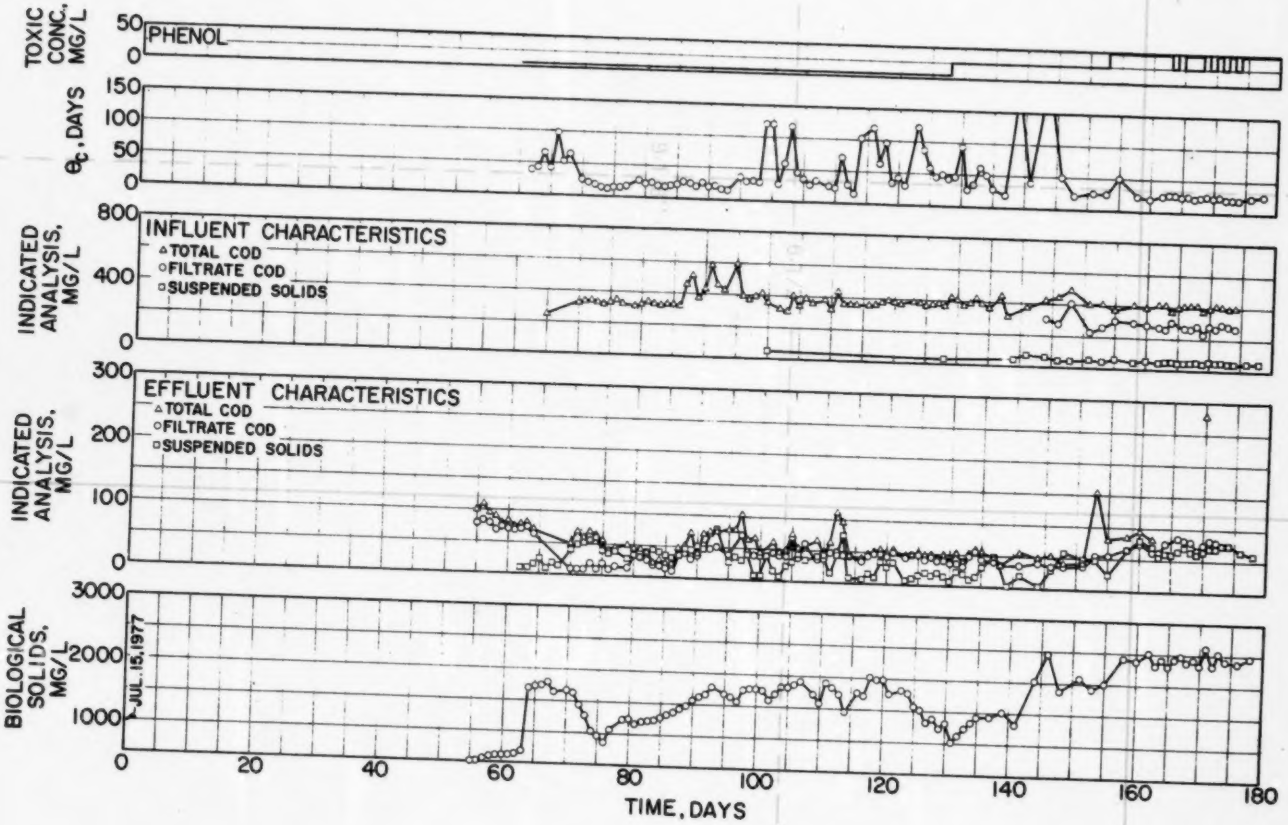

Figure 82. Operational results of continuous flow phenol unit (extended aeration).

shock loadings at the end of the experimental period, the effluent COD did not increase to the extent experienced for the faster growing sludge of Figure 78.

A study of substrate removal rate using sludge taken from the extended aeration unit three days after the dosage of phenol had been increased to 50 mg/l is shown in Figure 83. Substrate removal rates in the presence of 0,20 and 50 mg/l phenol were very similar.

Statistical analysis on the operational data obtained from the extended aeration process during the various periods of loading is shown in Table 19. It is seen that on average all dosages caused a somewhat higher total effluent COD than was observed for the faster growing sludge in the control unit. After acclimation to 20 mg/l of phenol in the feed, the total COD in the effluent was not very much different from the total COD in the effluent prior to beginning the dosage. At the dosage of 50 mg/l it was considerably higher. However, enough time may not have elapsed for the system to become acclimated. During the period when the dosage was cycled between 25 and 50 mg/l, filtrate COD and suspended solids in the effluent were considerably higher than they were at the 20 mg/l dosage or at no dosage. In general, it can be seen by comparing Figures 78 and 82 and the respective statistical analyses (Tabls 18 and 19) that the extended aeration unit was subject to a lesser amount of deterioration in effluent quality than was the faster growing activated sludge. Microscopic examinations made during the experimental period indicated there were rather large amounts of filamentous growth in the extended aeration sludge as well as in the faster growing sludge. The onset of filamentous growth in both units corresponded with the beginning of phenol dosage and the filamentous growth continued to increase as phenol dosage was increased. However, it increased at a significantly slower rate in the extended aeration sludge than in the faster growing biomass.

It is important to note that the results of both continuous flow pilot plant studies ($\mu_n = 0.2$ days^{-1} and extended aeration) provide indication that phenol added at relatively low concentrations to municipal sewage does have a deleterious effect upon the performance of the system. The results obtained with the batch activated sludge pilot plant dosed with phenol would give the impression of the need for less caution in regard to levels of this toxicant in a municipal waste stream than are determinable from these continuous flow studies. That is, the conclusions one would draw from analysis of the batch activated sludge data and the continuous flow activated sludge pilot plant data would not be the same. Also, in respect to the performance of the continuous flow pilot plants the overall impression one gets by analyzing the results is that the slower growing system provided better effluent quality and more stability against fluctuating loadings of the toxicant.

Control Unit, $\mu_n = 0.2$ days^{-1}

Operational data for the undosed control system during the first half of 1978 is shown in Figure 84. It is seen that in the early part of 1978 there were very wide variations in the COD of the municipal sewage from

EPA-287 (Cin.)
(4-76)

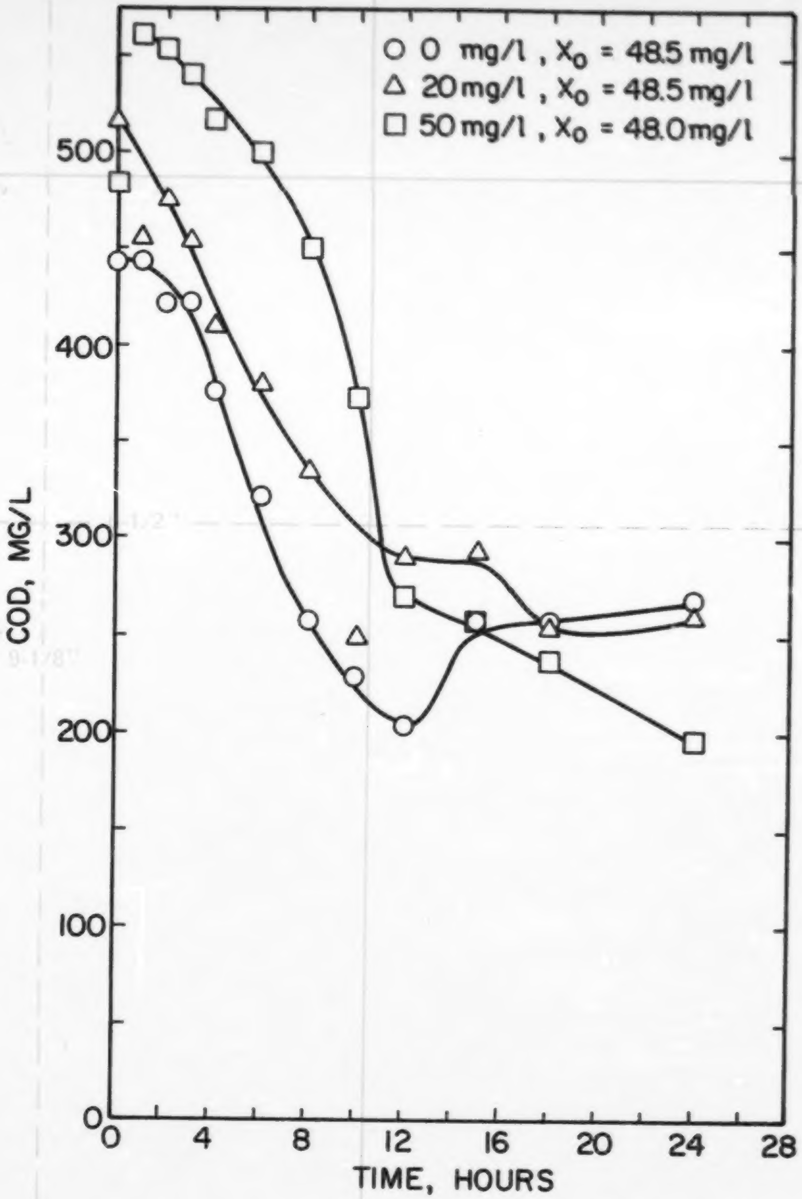

Figure 83. COD removal of continuous flow phenol unit (extended aeration) dosage=50 mg/l

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE ARE
OUTSIDE DIMENSION
FOR TABLE
AND ILLUS
TRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 19. STATISTICAL ANALYSIS OF OPERATIONAL DATA FOR AN EXTENDED AERATION PROCESS DOSED WITH PHENOL

Date	Parameter	PHENOL							Remarks
		FEED				EFFLUENT			
			COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
9/17/77 to 10/13/77	N	0	21	0	25	21	21	25	No toxic compound added.
	X	-	350.1	-	1371.4	48.2	23.8	36.7	
	σ	-	56.9	-	263.9	15.6	13.4	12.8	
	C.V.%	-	16.0	-	19.0	32.0	57.0	35.0	
	Range	- - -	252 - 520	- - -	860 - 1800	24 - 72	10 - 64	10 - 60	
10/14/77 to 11/19/77	N	1	32	0	33	31	31	33	5 mg/1 toxic compound added.
	X	48	391.7	-	1734.2	62.0	45.9	29.8	
	σ	-	60.9	-	152.7	18.4	8.9	19.6	
	C.V.%	-	16.0	-	9.0	30.0	19.0	66.0	
	Range	- -	312 - 596	- -	1320 - 2020	44 - 112	36 - 72	8 - 80	
11/20/77 to 12/15/77	N	8	16	5	16	16	16	16	20 mg/1 toxic compound added.
	X	52.1	403.5	297.4	1545.6	54.7	41.1	25.6	
	σ	13.3	41.0	68.8	405.8	27.7	6.8	16.9	
	C.V.%	25.0	10.0	23.0	26.0	51.0	17.0	66	
	Range	36 - 75	316 - 492	231 - 410	1024 - 2460	36 - 155	33 - 57	4 - 58	
12/16/77 to 12/25/77	N	5	5	5	5	4	5	5	50 mg/1 toxic compound added.
	X	51.6	398.6	283.2	2329.2	86.5	64.2	58.8	
	σ	6.4	14.7	18.7	191.9	7.4	7.7	21.4	
	C.V.%	12.0	4.0	7.0	8.0	9.0	12.0	36.0	
	Range	44 - 60	374 - 409	260 - 307	2012 - 2518	83 - 97	55 - 76	24 - 80	
12/26/77 to 1/9/78	N	13	11	10	13	1	10	13	Cyclic changes.
	X	49.2	398.4	275.3	2422.8	281.0	78.2	66.1	
	σ	4.0	13.4	20.4	84.3	-	5.6	5.5	
	C.V.%	8.0	3.0	7.0	3.0	-	7.0	8.0	
	Range	45 - 55	374 - 412	231 - 307	2310 - 2618	-	66 - 86	60 - 75	

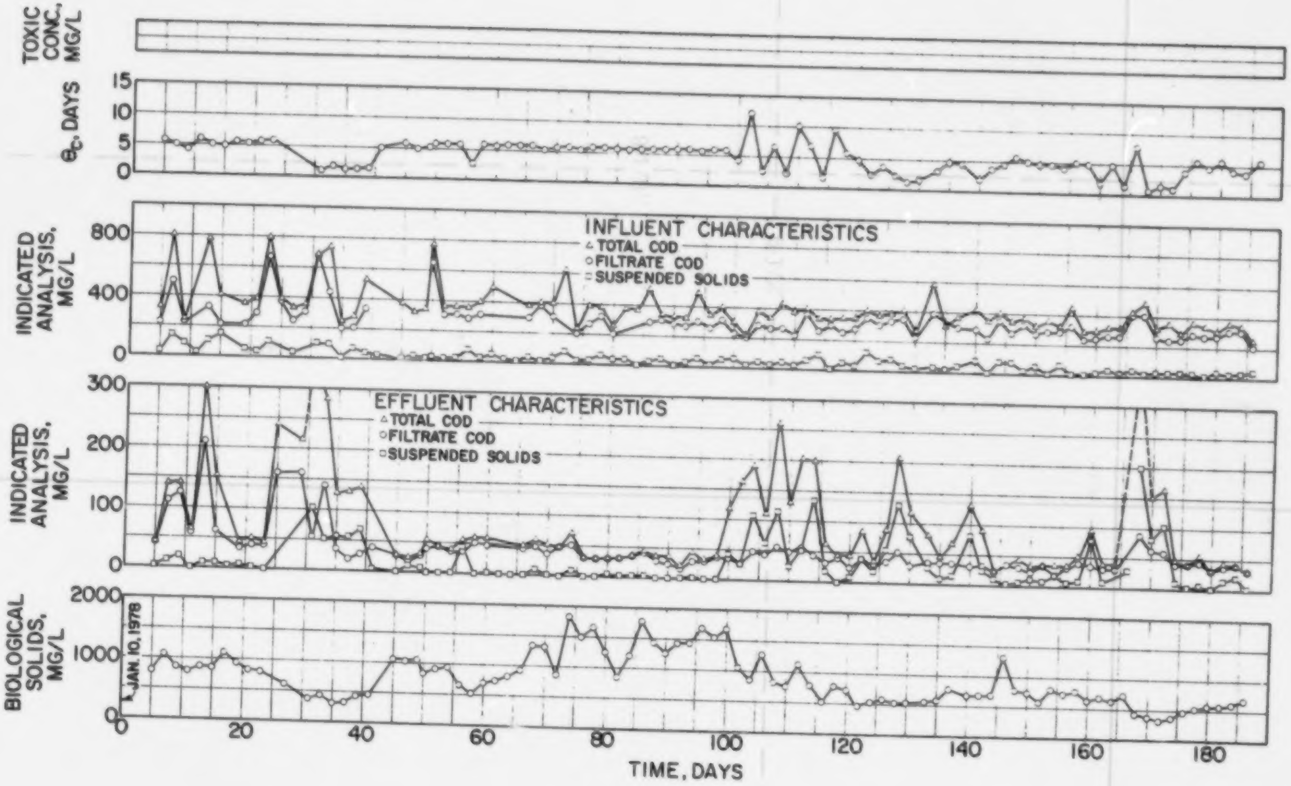

Figure 84. Operational results of continuous flow control (θ_c=5 days), from January 1978

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Stillwater. These periodic shocks caused a considerable loss of soluble COD in the pilot plant effluent. Also, it is apparent that the suspended solids concentrations in the effluent was higher than for the previous period of operation (see Figure 73). During the late winter and in the spring of 1978 the effluent soluble COD was rather low; however, there were periods of excessive leakage of suspended solids in the effluent.

Nitrobenzene, $\mu_n = 0.2$ days^{-1}

Figure 85 shows the performance of the continuous flow pilot plant which was dosed with varying concentrations of nitrobenzene. The wide swings in the feed concentration (shown in Figure 84) are not seen in this figure because on those days when the inflowing COD was high and there was foaming in the sewage it was diluted with tap water. This was done because it was feared that there could be toxic and/or foaming components in the municipal sewage which could cause effects which might not be due to nitrobenzene. Thus, in feeding this unit, changes in the feed were made on February 2, 12 and 28 of 1978. On these days the sewage was diluted with three parts of tap water. The glucose supplement of 200 mg/1, however, was always added.

It is seen that at dosages of 5 and 20 mg/1 of nitrobenzene, the soluble COD was in general below 50 mg/1, with the exception of the abnormally high values noted in late January and early February of 1978. The effluent suspended solids concentration was fairly low. It should be noted that throughout this period of operation the mixed liquor suspended solids were considerably higher than they were in the control unit. When the dosage was increased to 50 mg/1 in the feed, the suspended solids concentration in the effluent rose significantly, and there was an extremely high increase in soluble COD in the effluent. It is not known whether this increase was due solely to the increase in nitrobenzene because the increase coincided with a period of foaming in the municipal sewage. In any event, the system soon acclimated to the 50 mg/1 dosage as seen by the relatively low soluble COD and suspended solids in the effluent. During this dosage period the biomass concentration in the system gradually decreased. In response to fluctuating the nitrobenze loading, beginning in early May and extended into June, there was a serious leakage of biological solids. The suspended solids concentration in the effluent was higher than it was at the steady dosage of 50 mg/1.

The comparative trends observed by studying Figures 84 and 85 are verified by the results of the statistical analyses which are shown in Table 20. Suspended solids concentration in the test unit effluent was lower than in that of the control unit during the period of dosage of 5 mg/1. During the period of dosage at 25 mg/1 the control unit gave a better effluent, but when the dosage was raised to 50 mg/1 the test unit exhibited, on an average, less suspended solids in the effluent. However, there was a considerably higher suspended solids concentration in the effluent of the test unit when it was subjected to cyclic loadings, even at progressibely lower dosage levels than the highest steady state level. Also, the soluble COD in the effluent was slightly higher than it was in the control unit. It is interesting to note that the deleterious effects corresponding to the period of cyclic loading

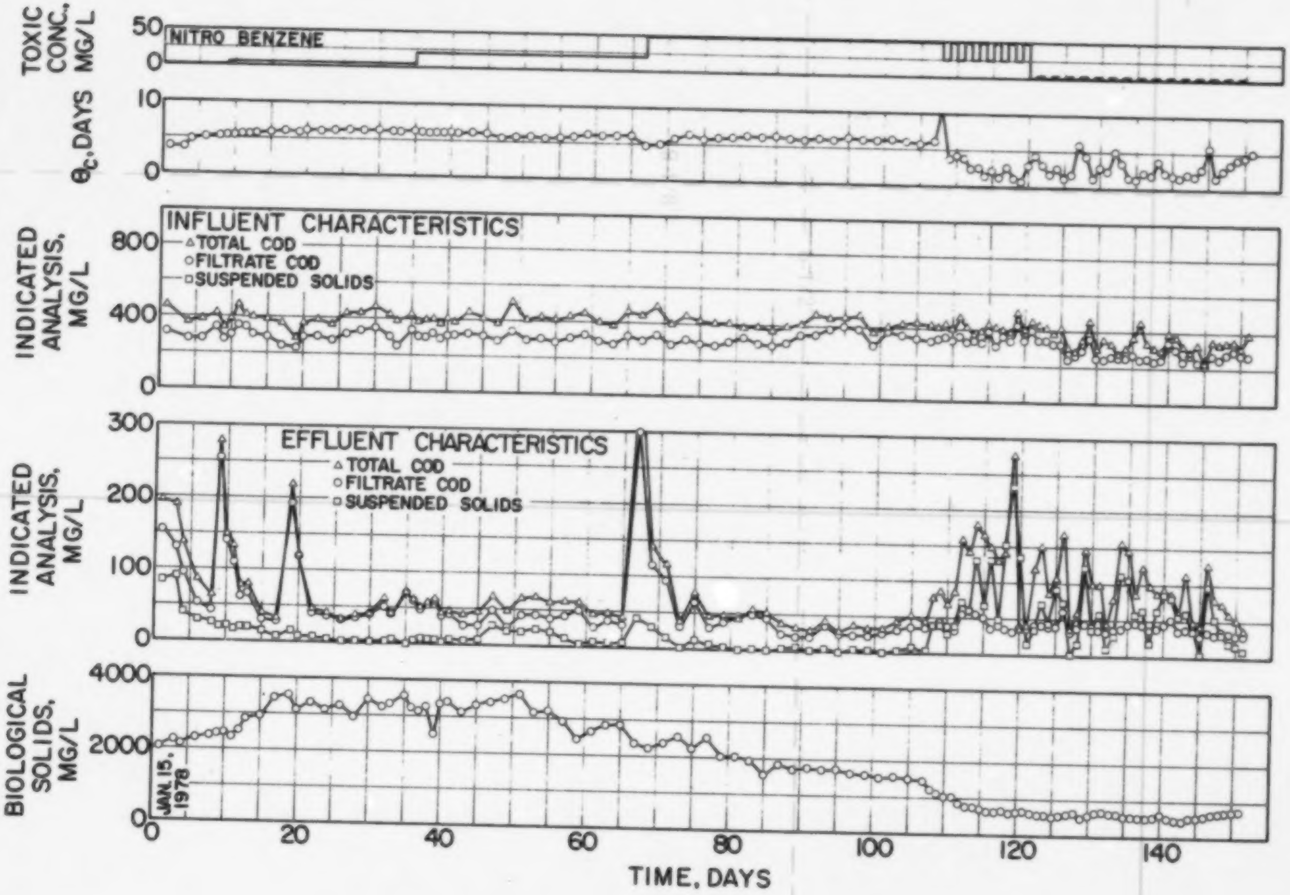

Figure 85. Operational results of continuous flow nitrobenzene unit (θ_c=5 days).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 20. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH NITROBENZENE

Date	Parameter	CONTROL							NITROBENZENE							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/16/78 to 1/24/78	N	4	3	3	4	4	3	3	0	5	5	6	6	6	6	No toxic compound added
	X	98.0	612.0	353.0	895.0	162.0	126.5	10.6	-	396.2	299.8	2258.3	158.3	121.7	48.5	
	σ	56.0	317.3	135.3	120.8	99.9	62.6	8.3	-	46.8	29.4	148.6	79.1	78.0	30.5	
	C.V.%	57.1	51.8	38.4	13.5	61.6	49.5	77.9	-	11.8	9.8	6.6	50.0	64.1	62.9	
	Range	28 - 164	246 - 809	226 - 496	788 - 1068	63 - 301	59 - 210	0 - 20	-	342 - 461	276 - 343	2054 - 2432	64 - 278	44 - 255	21 - 90	
1/25/78 to 2/19/78	N	10	12	12	11	11	11	10	0	16	16	16	16	16	16	5 mg/1 toxic compound added.
	X	75.6	464.7	350.0	642.2	166.7	73.6	36.8	-	401.9	302.7	3099.5	76.4	69.0	9.9	
	σ	43.6	183.8	168.0	278.9	110.8	62.7	36.5	-	43.8	37.4	384.7	53.0	47.7	7.4	
	C.V.%	57.7	39.6	48.1	43.4	66.5	85.2	99.1	-	10.9	12.4	12.4	64.9	69.1	74.4	
	Range	12 - 156	252 - 800	200 - 680	308 - 1108	44 - 400	20 - 212	0 105	-	290 - 468	232 - 357	2342 - 3587	32 - 219	28 - 194	0 - 22	
2/20/78 to 3/23/78	N	16	13	8	16	13	14	16	0	19	19	19	19	19	19	20 mg/1 toxic compound added.
	X	40.2	435.4	360.6	890.4	46.9	39.0	5.3	-	419.5	311.5	3082.6	70.9	55.6	13.0	
	σ	21.8	130.4	121.1	246.5	12.2	9.5	11.3	-	32.5	19.0	371.7	71.3	60.2	10.2	
	C.V.%	54.3	30.0	33.6	27.7	26.0	24.4	213.2	-	7.7	6.1	12.1	101.6	108.2	78.8	
	Range	20 - 92	326 - 780	288 - 652	456 - 1344	26 - 60	18 - 52	0 - 45	-	379 - 506	286 - 363	2391 - 3652	42 - 363	26 - 300	4 - 42	
3/24/78 to 5/3/78	N	20	20	18	20	20	20	20	0	21	21	21	21	21	21	50 mg/1 toxic compound added.
	X	40.9	365.6	273.7	1326.4	81.3	36.8	23.1	-	422.4	334.2	1852.7	52.9	41.0	7.3	
	σ	18.2	73.2	45.2	332.5	67.9	10.9	35.8	-	31.2	37.5	370.7	29.0	24.6	9.9	
	C.V.%	44.6	20.0	16.5	25.1	83.5	29.6	155.2	-	7.4	11.2	20.1	54.9	59.5	135.4	
	Range	2 - 68	220 - 518	202 - 372	764 - 1832	20 - 261	16 - 56	0 - 115	-	376 - 496	286 - 406	1214 - 2560	29 - 142	20 - 116	0 - 38	
5/4/78 to 6/15/78	N	21	21	20	21	20	21	21	0	43	43	43	43	43	43	Cyclic changes
	X	55.5	376.9	299.4	686.5	73.4	33.6	34.2	-	362.0	302.1	658.3	102.6	40.2	62.4	
	σ	36.2	62.8	42.1	177.5	47.7	7.3	39.6	-	68.2	51.9	140.0	49.5	8.0	45.9	
	C.V.%	65.2	16.7	14.1	25.8	65.0	21.6	115.9	-	18.8	17.2	21.3	48.3	20.0	73.6	
	Range	5 - 148	277 - 391	229 - 391	528 - 1312	24 - 208	20 52	0 - 135	-	229 - 496	224 - 436	484 - 1118	36 - 276	30 - 61	2 - 234	

EPA-287 (Cin.)
(4-76)

also fit the general experience from the operation of the batch systems.

It had been seen from stripping tests made in the batch activated sludge units that nitrobenzene is only slightly strippable under the conditions of these experimentations. A batch experiment run using as an initial inoculum some of the excess sludge from the pilot plant is shown in Figure 86 and it is seen that there is little difference between the course of COD removal in the undosed sludge and the systems receiving either 5 or 20 mg/l nitrobenzene. The sludge had been acclimated to the 5 mg/l dosage level in the continuous flow unit for approximately 3 weeks prior to running the experiment shown in the figure.

The general conclusion one can make from these studies is that under a steady diet of nitrobenzene, fed along with the components of municipal sewage, there appears to be a considerable ability to handle this compound. However, under conditions where the concentration of nitrobenzene fluctuates there is cause for concern, particularly in regard to possible effects on the flocculation and settling of the biomass.

2-Chlorophenol, $\mu_n = 0.2$ days^{-1}

Figure 87 shows the response of the continuous flow unit to varying dosages of 2-chlorophenol, and in Table 21 statistical analyses for these results are compared with those for the control unit during the same period of operation. In studying this compound, the same procedure which was followed in studying nitrobenzene was used. That is, the unit was not subjected to high peak sewage COD as was the case for the control. On January 23 and February 2, 12 and 28, 1978, when the municipal sewage was foamy and exhibited an extremely high COD, the sewage was diluted (1 part sewage to 3 parts water) with tap water.

It is seen that after a short acclimation period, the system could accommodate rather well to the 5 mg/l level of 2-chlorophenol. However, the suspended solids concentration in the effluent was rather high. It is important to note that the effluent suspended solids concentration in this unit before beginning dosage was considerably higher than in the control. It became progressively worse as the dosage was increased. In general, the performance was not as good as the performance of the control unit. The same general trend was observed for the behavior of this compound in the batch pilot plants as well. It seems from these results that one may expect that 2-chlorophenol will lead to higher effluent suspended solids concentrations. Analyses made for 2-chlorophenol in the mixed liquor and the effluent at the 5 and 20 mg/l dosages (no analyses at 50 mg/l) indicated the presence of only trace quantities.

As can be seen from Figure 88 the test compound was strippable under the conditions of these experimentations to approximately the same degree as it was under the conditions of the batch pilot plant operations, i.e., only rather slowly.

EPA-287 (Cin.)
(4-76)

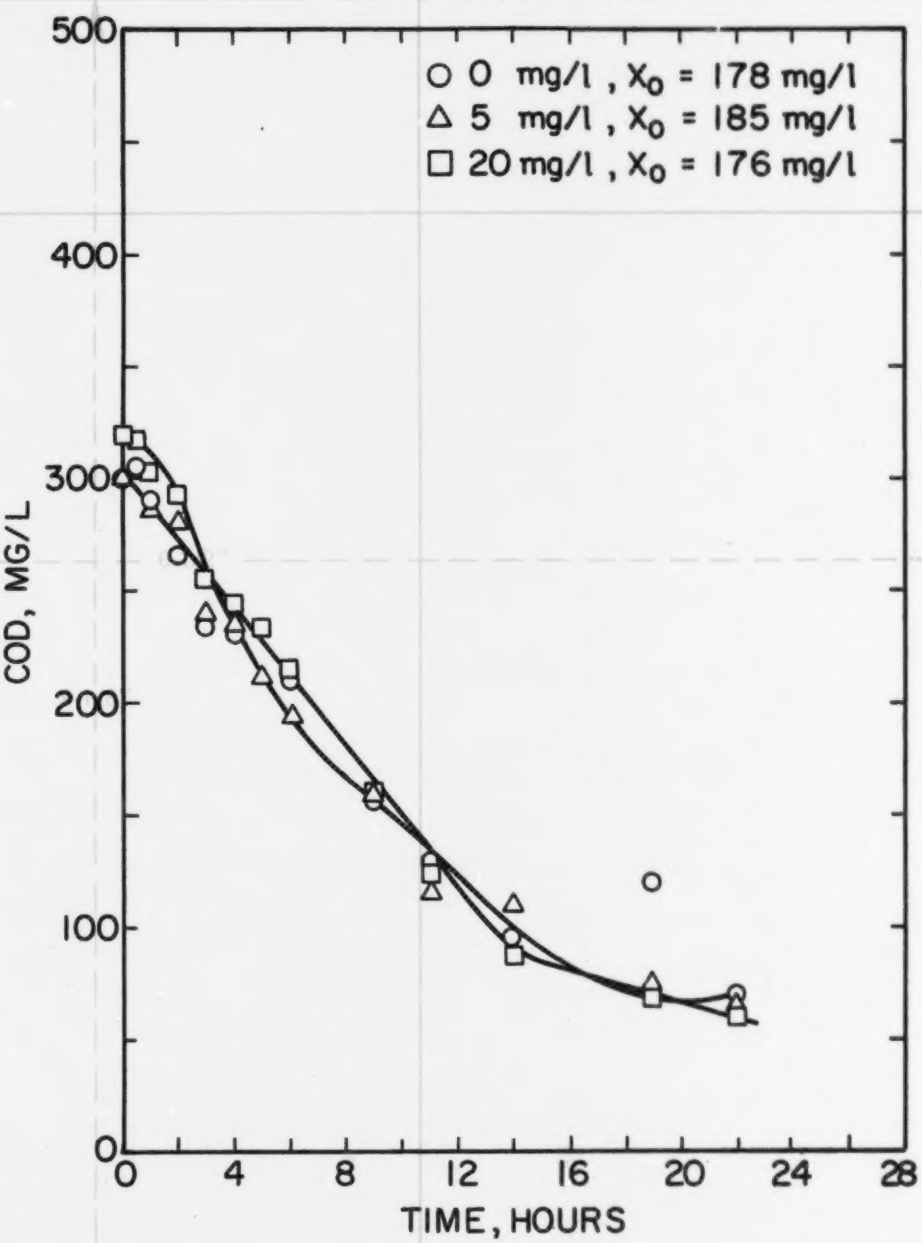

Figure 86. COD removal of continuous flow nitrobenzene unit (θ_c=5 days) dosage=5 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

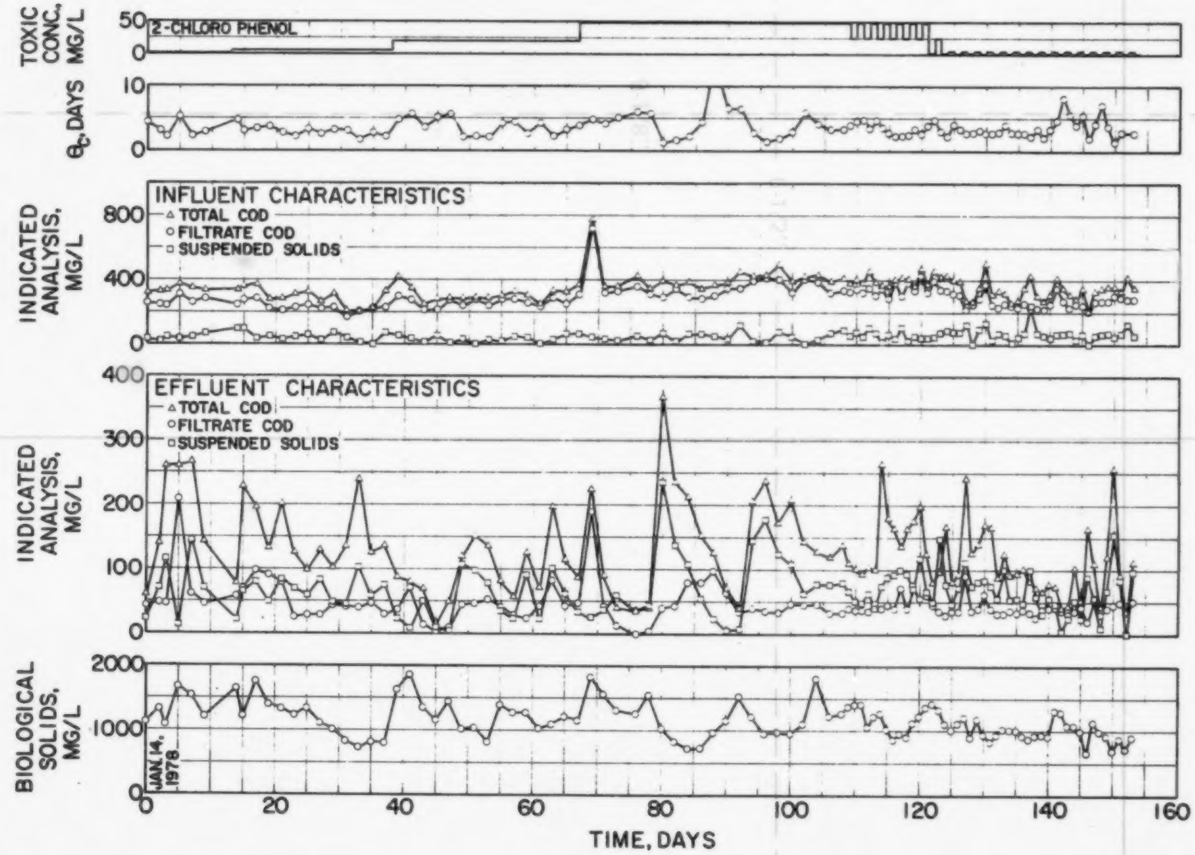

Figure 87. Operational results of continuous flow 2-chlorophenol unit (θ_c=5 days).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 21. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH 2-CHLOROPHENOL

Date	Parameter	CONTROL							2-CHLOROPHENOL							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/10/78 to 1/27/78	N	8	7	7	9	7	7	9	9	9	9	0	10	10	10	No toxic compound added.
	X	87.5	449.6	279.3	904.9	53.1	44.0	2.8	61.2	258.6	254.0	1275.8	137.2	61.2	51.7	
	σ	52.0	242.6	105.0	112.2	12.6	7.3	4.2	66.4	24.4	27.5	255.9	95.5	53.2	49.7	
	C.V.%	59.4	54.0	37.6	12.4	23.7	16.6	151.0	108.5	9.4	10.8	20.0	69.6	86.9	96.2	
	Range	28 - 164	246 - 809	206 - 496	788 - 1068	32 - 72	32 - 52	0 10	20 - 235	261 - 478	220 - 308	875 - 1675	36 - 266	26 - 209	4 - 145	
1/28/78 to 2/21/78	N	10	11	11	10	10	10	9	13	13	13	13	13	13	13	5 mg/l toxic compound added.
	X	63.6	383	362.0	555.6	169.0	74.7	39.7	49.6	293.5	229.8	1171.3	148.7	52.8	65.1	
	σ	34.6	469.1	171.1	229.8	116.7	66.0	37.4	30.2	55.4	30.1	326.0	51.2	24.8	21.1	
	C.V.%	54.4	192.1	47.3	41.4	69.5	88.3	94.2	60.8	18.9	13.1	27.8	34.4	47.1	32.5	
	Range	12 156	252 800	200 680	308 936	44 400	20 212	0 - 105	0 - 96	204 - 368	168 284	732 - 1762	78 - 240	25 - 98	22 - 103	
2/22/78 to 3/22/78	N	14	12	8	14	12	12	14	15	15	15	15	15	15	15	20 mg/l toxic compound added.
	X	36.9	419.0	360.5	923.6	46.8	38.2	5.7	35.1	310.2	263.9	1253.5	96.4	39.7	50.3	
	σ	18.2	121.4	121.1	233.1	12.7	9.9	12.0	20.6	45.3	27.9	261.8	45.6	21.7	36.8	
	C.V.%	49.2	29.0	33.6	25.2	27.2	26.0	2.1	58.6	14.6	10.6	20.9	47.3	54.6	73.1	
	Range	20 - 92	326 - 780	288 - 652	536 - 1344	26 - 60	18 - 52	0 - 45	5 - 66	250 - 420	215 - 306	825 - 1860	14 - 198	4 - 84	5 - 108	
3/23/78 to 5/3/78	N	21	21	18	21	21	21	21	21	21	21	21	21	21	21	50 mg/l toxic compound added.
	X	43.3	378.2	273.7	1304.2	79.7	37.3	22.0	49.5	419.0	361.6	1209.7	147.7	50.0	80.8	
	σ	21.0	92.0	45.2	339.7	66.5	10.9	35.3	28.1	89.5	91.2	317.4	84.5	39.6	58.6	
	C.V.%	48.5	24.3	16.5	26.0	83.5	29.2	160.5	56.7	21.4	25.2	26.2	57.2	79.3	72.5	
	Range	2 - 92	220 632	202 - 372	764 - 1832	20.- 190	16 - 56	0 - 115	7 - 120	348 - 778	286 - 720	725 - 1838	36 - 370	0 - 190	5 - 236	
5/4/78 to 6/16/78	N	21	21	20	21	20	21	21	44	44	44	44	44	44	44	Cyclic changes
	X	55.5	376.9	299.4	686.5	73.4	33.6	34.2	63.8	358.2	291.9	1036.7	118.5	42.6	69.3	
	σ	36.2	62.8	42.1	177.5	47.7	7.3	39.6	39.7	63.4	55.1	225.5	55.1	13.4	34.2	
	C.V.%	65.2	16.7	14.1	25.8	65.0	21.6	115.9	62.3	17.7	18.9	21.8	46.5	31.5	49.3	
	Range	5 - 148	277 - 391	229 - 391	526 - 1312	24 - 208	20 - 52	0 - 135	0 - 237	204 - 456	204 - 428	662 - 1428	36 - 264	20 - 92	0 - 155	

BEGIN LAST LINE OF TEXT

3/8"

BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

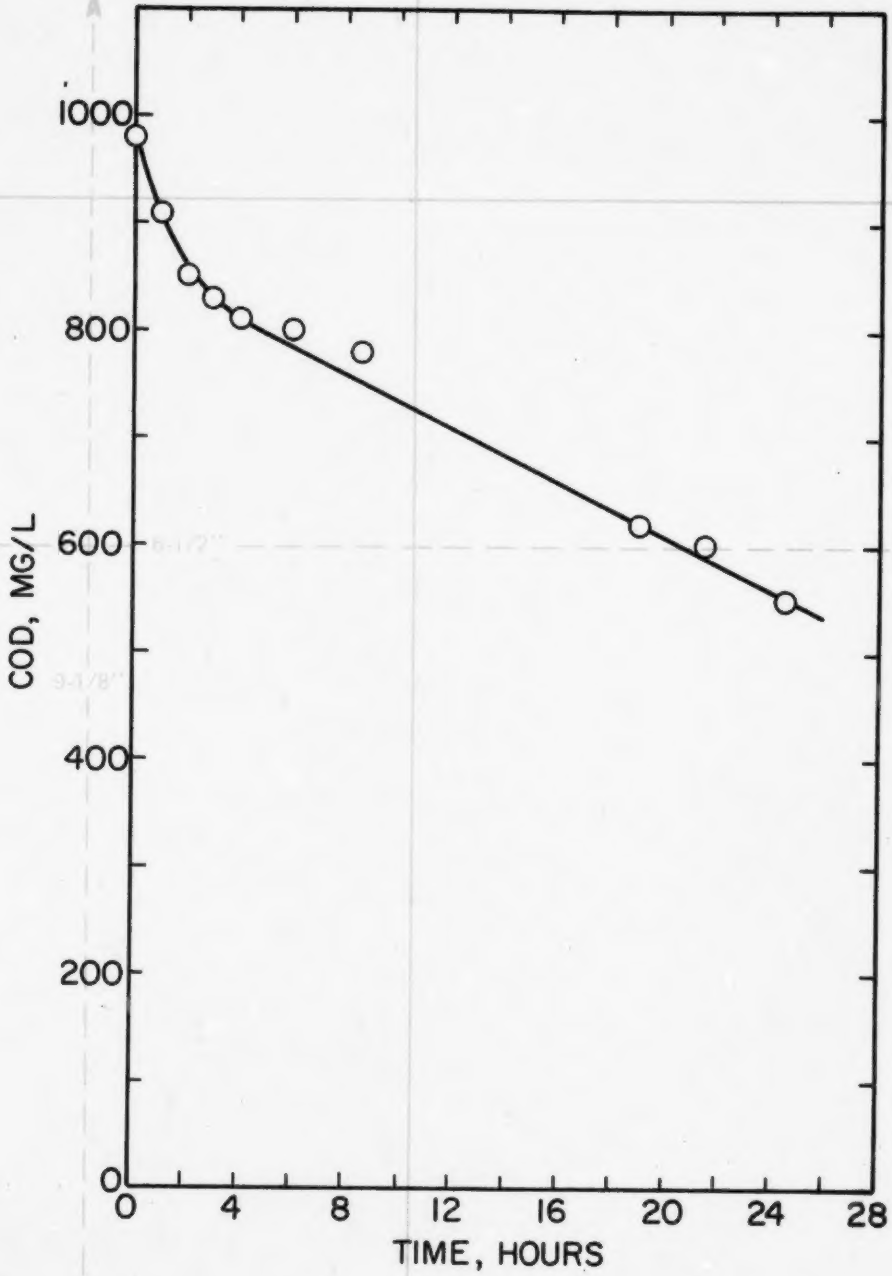

Figure 88. Batch stripping study of 2-chlorophenol in a continuous flow reactor.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Using excess sludge from the continuous flow pilot plant on March 17, 1978, after nearly one month of acclimation to a dosage of 20 mg/l, the rate of removal was more rapid in an undosed control than in the systems dosed with 25 or 50 mg/l of the test compound (Figure 89).

2-Chlorophenol, Extended Aeration

Figure 90 shows the performance of the extended aeration activated sludge pilot plant beginning on January 15, 1978. This activated sludge pilot plant had previously been receiving phenol as a test compound. However, the system had not been fed the previous test compound for at least 15 days prior to January 15 when this data taking period was initiated. In feeding the extended aeration pilot plant, the municipal sewage was not diluted to counteract its periodic foaming tendency and abnormally high COD. However, on February 2 and on March 2 and 24, 1978 only one-half of the glucose supplement was added; these were days of generally high COD in the sewage. It is important to note that the feed COD was not sampled by each investigator on the same days; thus, the identical rising and falling trends are not observed on each graph. Statistical analyses of these data are shown in Table 22.

During February there was a falling trend in the biomass concentrations; unlike the control system shown in Figure 84 there was no foaming in the extended aeration unit and the suspended solids concentration in the effluent was rather low. Soluble COD in the effluent, was, on an average, better than it was in the control system even though the extended aeration pilot plant was receiving dosages of 5 to 25 mg/l of 2-chlorophenol. In general, during this period the effluent from the extended aeration unit was comparable to that of the control and was considerably better than that for the faster growing activated sludge which received similar dosage of the test compound. Shortly after increasing the dosage to 50 mg/l, there was a noticeable change in predominant species and in the appearance of the sludge. There was a decrease in protozoan population and a concomitant increase in effluent suspended solids concentration. However, within three weeks the effluent solids concentration returned to its normally low level and remained so during the $50 \longrightarrow 25 \longrightarrow 50$ mg/l and the $25 \longrightarrow 0 \longrightarrow 25$ mg/l pulsating loading period. Throughout the remainder of the experimentation, the protozoan population increased but was not totally restored to the high level of activity observed before increasing the concentration to 50 mg/l in the feed.

A sample of the batch studies run using an inoculum of cells obtained from the extended aeration pilot plant is shown in Figure 91. At the time of running this experiment the activated sludge had been exposed to a loading level of 5 mg/l of 2-chlorophenol for approximately three weeks. It is seen that the rate of removal of COD was more rapid in the undosed control for several hours but the rates were approximately the same thereafter.

Control Unit, $\mu_n = 0.2$ days^{-1}

The performance of the activated sludge pilot plant used as the undosed

EPA-287 (Cin.)
(4-76)

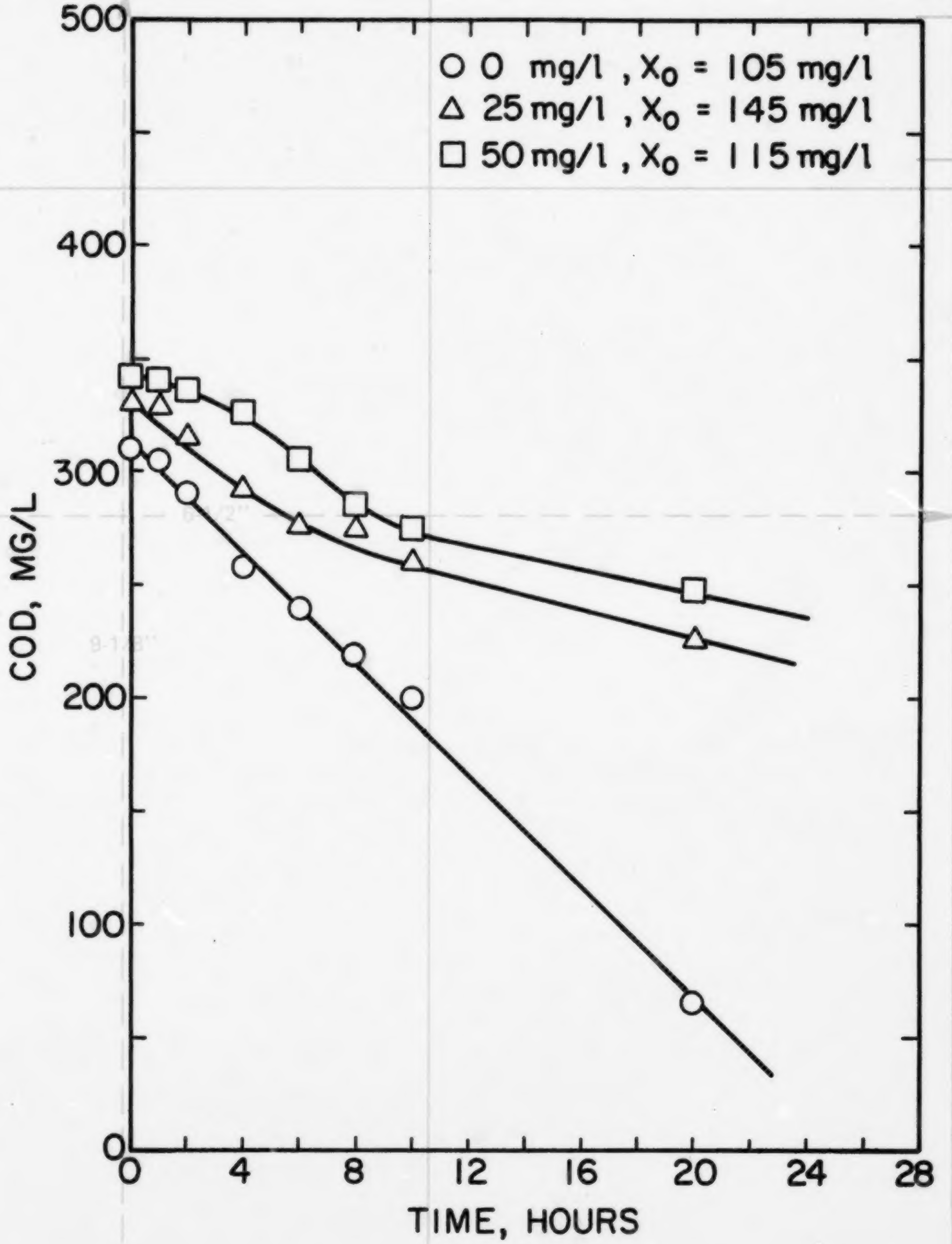

Figure 89. COD removal of continuous flow 2-chlorophenol unit (θ_c=5 days), dosage=20 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

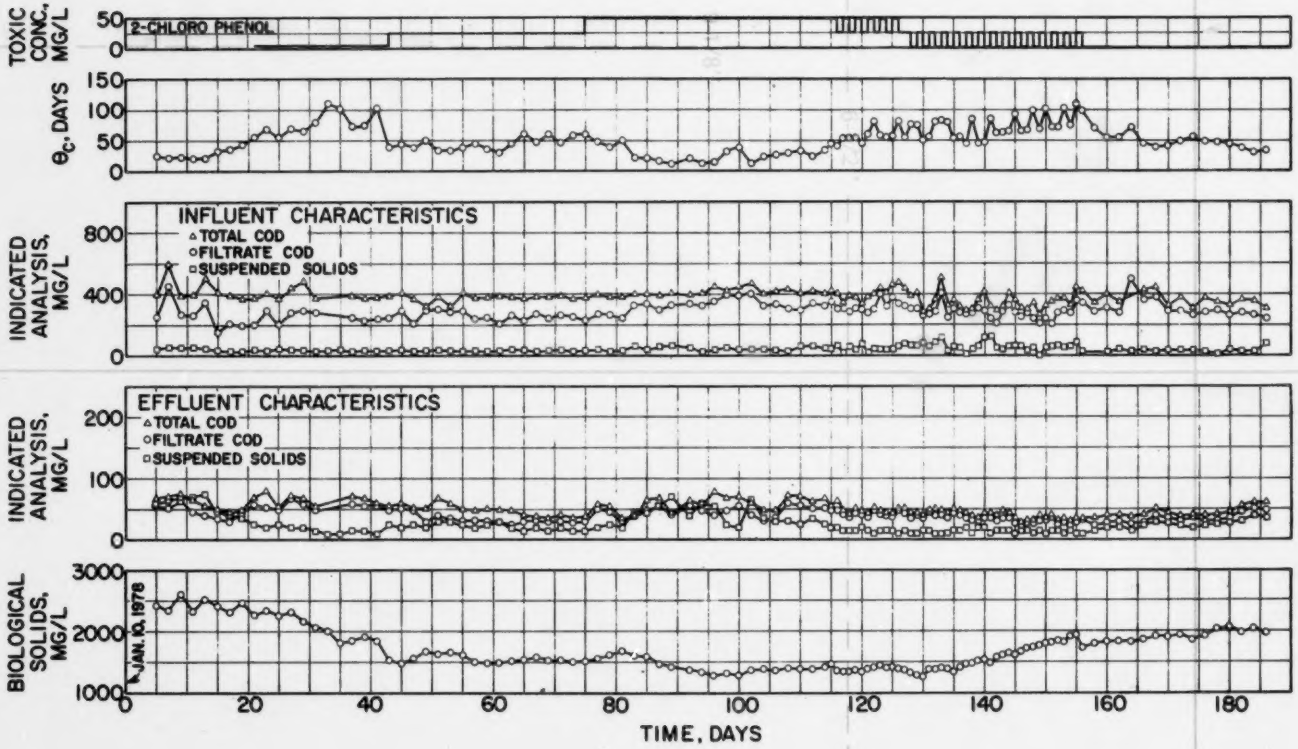

Figure 90. Operational results of continuous flow 2-chlorophenol unit (extended aeration).

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

TABLE 22. STATISTICAL ANALYSIS OF DATA FOR AN EXTENDED AERATION PROCESS DOSED WITH 2-CHLOROPHENOL

Date	Parameter	2-Chlorophenol							Remarks
		FEED				EFFLUENT			
			COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/15/78	N	9	9	9	9	9	9	9	No toxic
to	X	42.8	427.8	263.0	2414.0	61.1	47.0	53.9	compound
1/31/78	σ	9.7	73.7	91.8	110.5	11.4	11.1	18.0	added.
	C.V.%	22.7	17.2	34.9	4.6	18.6	23.7	33.4	
	Range	30 - 55	373 - 596	158 - 458	2280 - 2618	45 - 76	30 - 64	25 - 75	
2/1/78	N	11	9	9	11	9	9	11	5 mg/1
to	X	35.9	404.9	260.1	2010.9	65.1	55.1	16.8	toxic
2/22/78	σ	4.4	38.8	29.9	252.3	9.7	6.2	5.6	compound
	C.V.%	12.2	9.6	11.5	12.6	14.9	11.2	33.4	added.
	Range	30 - 45	373 - 490	212 - 296	1520 - 2340	53 - 82	48 - 67	10 - 25	
2/23/78	N	16	16	16	16	16	16	16	25 mg/1
to	X	35.3	379.5	260.8	1550.0	48.2	33.1	32.8	toxic
3/26/78	σ	4.6	24.4	30.0	64.0	9.6	7.3	44.9	compound
	C.V.%	13.2	6.4	11.5	4.1	19.8	22.0	136.9	added.
	Range	30 - 45	322 - 412	212 - 301	1480 - 1680	36 - 69	25 - 52	15 - 30	
3/27/78	N	21	21	21	21	21	21	21	50 mg/1
to	X	46.9	418.0	330.2	1374.7	60.0	46.8	36.4	toxic
5/3/78	σ	12.8	22.7	40.0	37.1	11.6	8.2	16.3	compound
	C.V.%	27.3	5.4	1.2	2.7	19.4	17.6	44.8	added.
	Range	25 - 65	386 - 476	252 - 408	1280 - 1680	35 - 72	31 - 60	20 - 70	
5/4/78	N	40	40	40	40	40	40	40	Cyclic
to	X	58.6	369.3	295.8	1526.0	42.6	35.6	13.8	changes.
6/15/78	σ	27.2	57.5	46.2	193.2	6.6	6.3	3.2	
	C.V.%	46.4	15.6	15.6	12.7	15.5	17.7	23.2	
	Range	0 - 130	284 - 512	212 - 418	1260 - 1940	28 - 52	24 - 48	10 - 20	

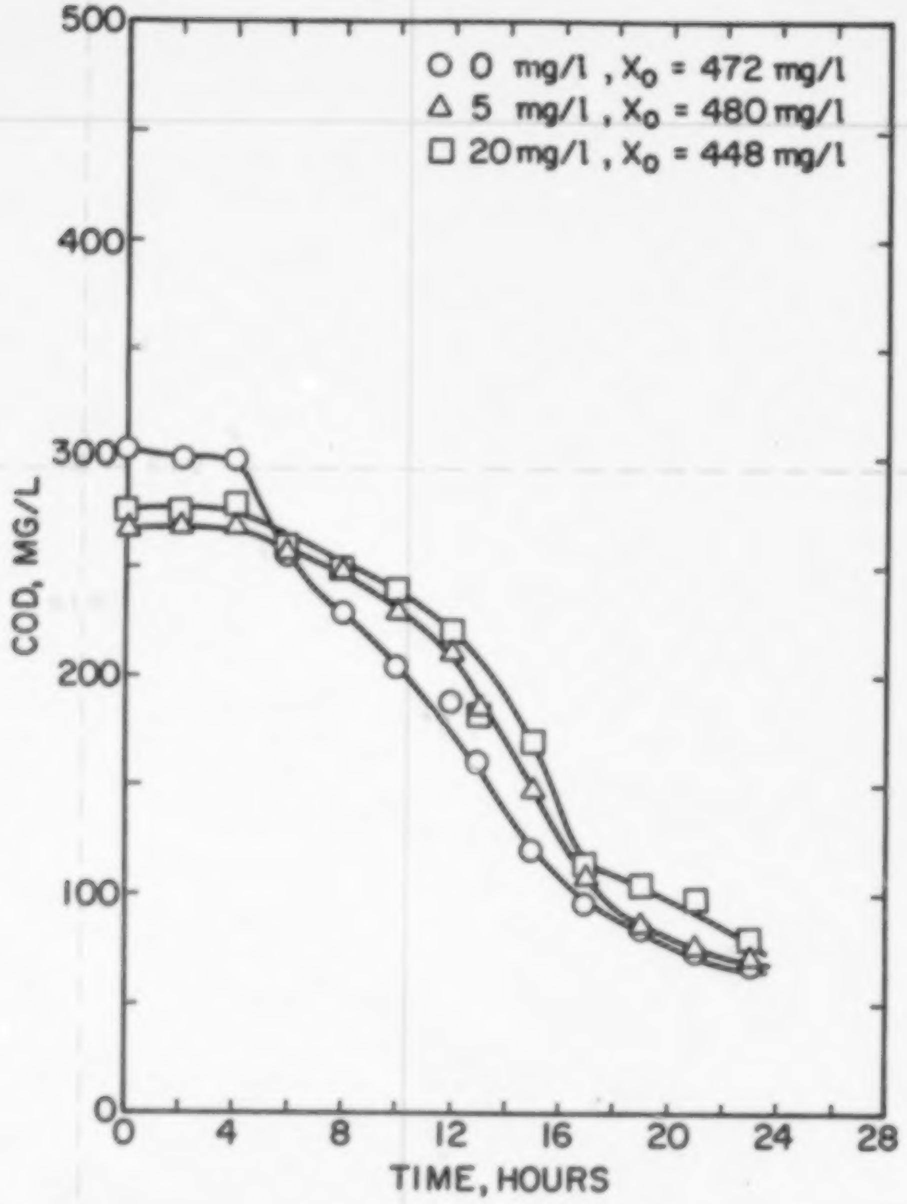

Figure 91. COD removal of continuous flow 2-chlorophenol unit (extended aeration), dosage=5 mg/l.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA 287 (Cin.)
(4-76)

control during this period of experimentation (6/20/78 - 10/1/78) is shown in Figure 92. It is seen that the COD of the municipal sewage of Stillwater continued to be subject to periodic changes but that on an average, the municipal sewage supplemented with 200 mg/l of glucose exhibited a COD between 300 and 400 mg/l as it did during the previous year of study. The soluble COD in the effluent was for the most part below 50 mg/l, but there were rather short periods when it rose to approximately 75 mg/l. For the most part, suspended solids concentrations in the effluent remained in the range of 10 to 20 mg/l but there were short lived periods when the values rose to unacceptable levels. In general, the periods of increased suspended solids concentration corresponded to periods of somewhat increased soluble COD in the effluent and decreased mixed liquor suspended solids concentration. The rise in effluent suspended solids concentration in early December coincided with a very noticeable shift in predominant species in the activated sludge. Protozoa disappeared and filamentous organisms increased. This represented a considerable change from the appearance of the sludge noted for microscopic observations made in mid-November.

Trichloroethylene, $\mu_n = 0.2$ days^{-1}

The performance of a continuous-flow activated sludge pilot plant treating municipal sewage dosed with varying concentrations of trichloroethylene is shown in Figure 93. Statistical analyses of this performance are compared with similar statistical analyses of the control data for the same operational period in Table 23. From a comparison of Figure 93 and Figure 92, showing performance of the control, it is apparent that the soluble COD in the effluent of both units was approximately the same through the dosing period from August 2 to September 5, 1978 (5 mg/l of toxicant added) and the period of September 6 to October 17 1978, during which time the test system received a dosage of 25 mg/l of trichloroethylene. Suspended solids and soluble COD in the effluent of the test unit were slightly higher than in the control but during the period of October 18 to November 14, 1978, when the test unit received 50 mg/l of the test compound, the average suspended solids and soluble COD in the effluent of the test unit were somewhat less than in the control. However, in response to the cyclic loading which began on November 15, 1978, the effluent suspended solids concentration rose to nearly 120 mg/l on an average and was above 200 mg/l at times during this period of operation. The soluble COD in the effluent was also somewhat higher than in the control unit. These results provide some indication that steady feeding of the test compound is more readily accomodated by the activated sludge than is cyclical or pulse loading.

Previous studies made in the batch units indicated that trichloroethylene was rapidly strippable under the conditions of this experimentation. Figure 94 shows the results of a batch experiment run on September 3, 1978 using a sample of excess sludge from the continuous flow unit which had been acclimated for one month to a level of 5 mg/l of trichloroethylene in the feed. It is seen that the removal of COD in the control was rather slow and that the overall removal of COD in the batch system dosed with an initial concentration of 5 mg/l of the test compound, as well as one dosed with 25

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

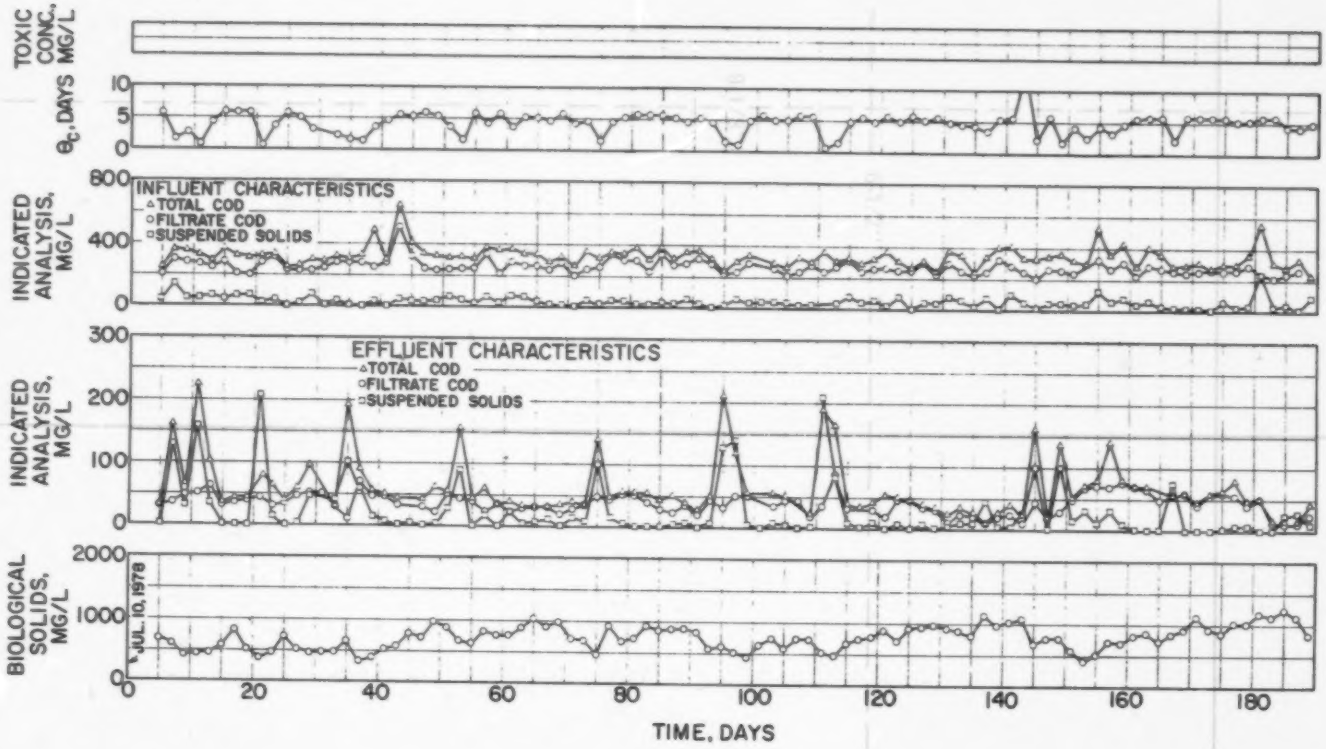

Figure 92. Operational results of continuous flow control (θ_c=5 days), from July 1978.

EPA-287 (Cin.)
(4-76)

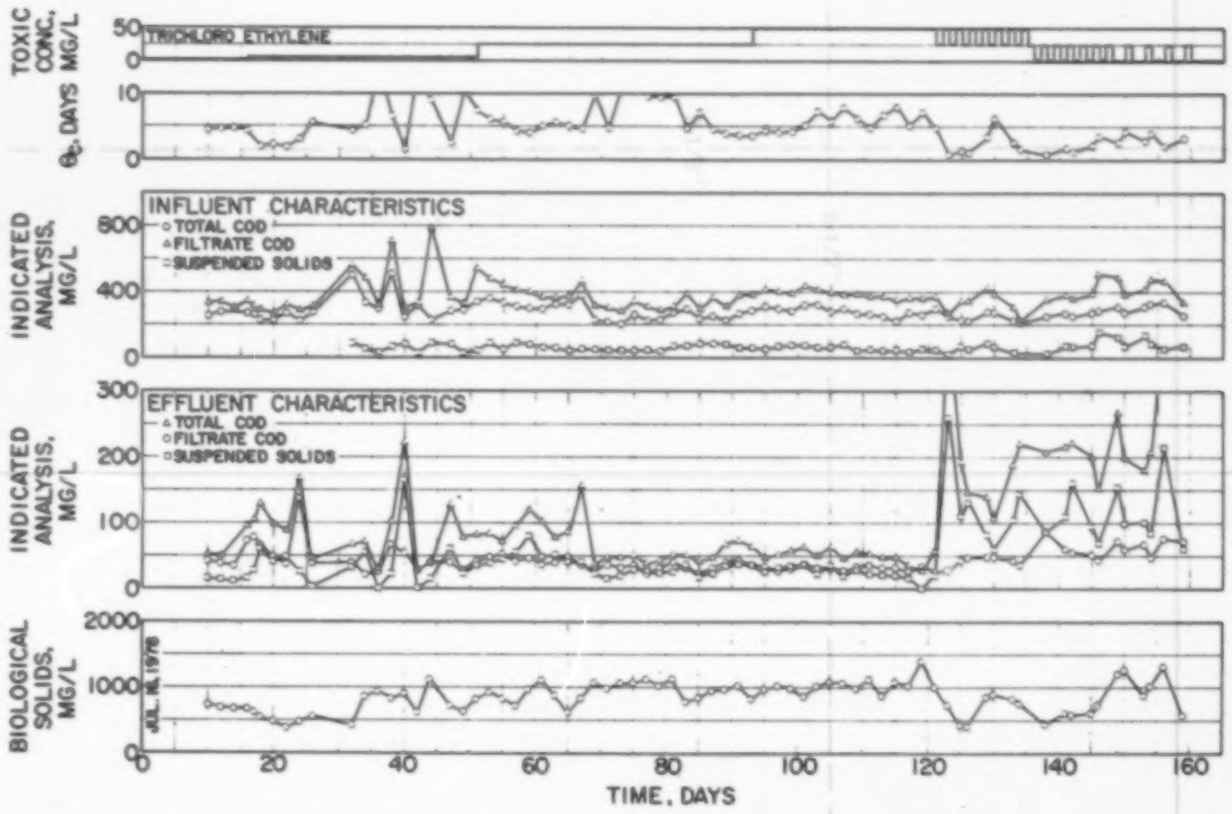

Figure 93. Operational results of continuous flow trichloroethylene unit (θ_c=5 days).

TABLE 23. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH TRICHLOROETHYLENE

Date	Parameter	CONTROL							TRICHLOROETHYLENE							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
7/26/78 to 8/1/78	N	3	3	3	3	3	3	2	-	4	3	4	3	4	4	No toxic compound added.
	X	54.7	322.0	232.7	565.3	56.0	40.0	0	-	331.5	269.0	692.5	66.0	46.5	14.5	
	σ	26.6	8.0	43.0	227.5	20.8	4.0	0	-	14.6	11.8	28.5	25.2	17.3	1.9	
	C.V.%	48.7	2.5	18.5	40.2	37.1	10.0	0	-	4.0	4.0	4.0	38.0	36.0	13.0	
	Range	24 - 72	314 - 322	203 - 282	372 - 816	44 - 80	36 - 44	0	-	310 - 342	256 - 279	668 - 732	50 - 95	35 - 73	12 - 16	
8/2/78 to 9/5/78	N	18	18	18	18	16	17	17	10	16	16	16	16	16	16	5 mg/l toxic compound added.
	X	37.8	350.6	282.8	621.3	72.1	40.1	26.1	60.3	409.3	301.2	683.1	92.9	49.7	39.1	
	σ	24.0	94.6	66.9	177.2	44.0	14.2	32.0	23.7	160.2	88.1	208.0	51.4	28.5	39.1	
	C.V.%	63.5	27.0	23.7	28.5	61.1	35.3	122.4	39.0	39.0	29.0	30.0	55.0	57.3	100.0	
	Range	0 - 72	249 - 657	229 - 516	336 - 984	32 - 193	12 - 72	0 - 102	30 - 90	272 - 792	221 - 508	392 - 1115	29 - 222	22 - 139	0 - 165	
9/6/78 to 10/17/78	N	21	21	21	21	21	21	21	21	21	21	21	21	21	21	25 mg/l toxic compound added.
	X	39.2	338.1	276.6	764.6	59.2	36.2	23.3	62.2	360.5	276.7	891.4	69.2	37.2	36.3	
	σ	19.7	38.7	40.0	174.0	44.7	10.8	42.6	18.0	56.7	49.9	225.1	29.6	7.6	15.0	
	C.V.%	50.3	11.5	14.4	22.8	75.5	30.0	182.6	29.0	15.7	18.0	25.3	42.7	20.3	41.3	
	Range	0 - 76	240 - 396	212 - 352	444 - 1048	28 - 212	20 - 52	0 - 140	40 - 92	280 - 480	204 - 362	635 - 1120	38 - 152	24 - 52	16 - 80	
10/18/78 to 11/14/78	N	13	13	13	14	12	12	14	14	14	14	14	14	14	14	50 mg/l toxic compound added.
	X	45.8	316.3	254.8	718.3	66.2	39.4	24.5	57.9	385.8	281.1	1032.3	50.6	31.0	24.4	
	σ	21.7	31.9	41.2	140.9	53.1	17.0	57.4	15.0	23.6	27.6	130.0	9.6	3.3	9.4	
	C.V.%	47.4	10.1	16.2	19.6	80.2	43.0	234.2	6.1	9.8	25.9	12.6	19.1	10.6	30.6	
	Range	8 - 84	264 - 375	154 - 320	472 - 936	23 - 190	19 - 84	0 - 210	36 - 80	348 - 432	224 - 320	860 - 1400	29 - 64	25 - 36	0 - 36	
11/15/78 to 12/22/78	N	19	19	18	19	18	19	19	17	18	18	18	17	18	18	Cyclic changes.
	X	52.8	356.2	265.7	808.6	62.0	40.0	21.8	74.6	380.4	268.6	786.1	216.2	54.9	118.2	
	σ	25.0	66.0	35.5	190.3	45.0	23.6	30.3	36.3	73.9	35.4	276.1	83.3	15.2	52.9	
	C.V.%	47.3	18.5	13.4	23.5	72.6	59.0	138.9	48.7	19.4	13.2	35.1	38.5	27.7	44.8	
	Range	16 - 104	245 - 528	219 - 334	412 - 1132	12 - 162	12 - 76	0 - 100	22 - 155	227 - 508	216 - 336	405 - 1315	107 - 412	28 - 86	60 - 260	

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6-1/2"

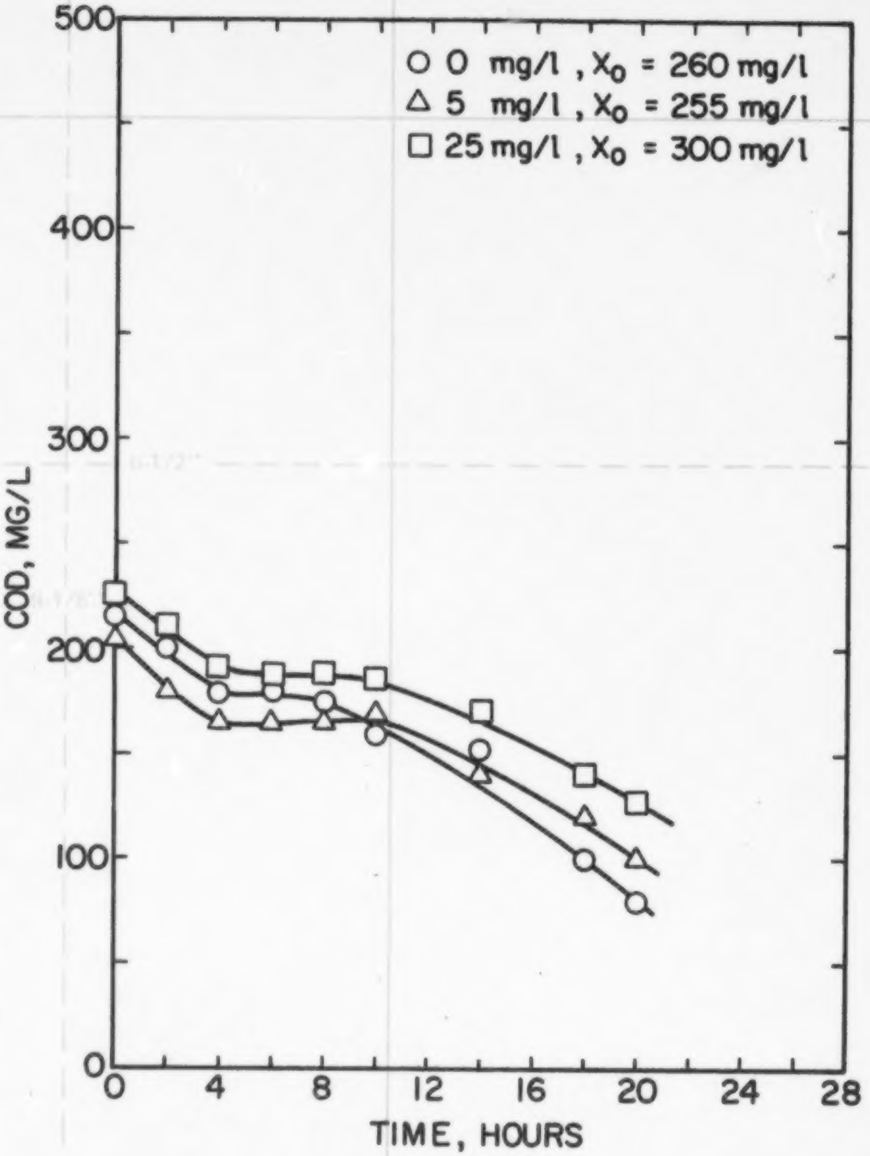

Figure 94. COD removal of continuous flow trichloroethylene unit (θ_c= 5 days), dosage=5 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

mg/l of trichloroethylene, was slightly slower than the control. Batch growth and substrate removal studies made after the continuous flow unit had been acclimated to a dosage of 25 mg/l of the test compound for a period of approximately 8 weeks indicated the same general finding. That is, the removal of COD in the control and the dosed batch reactors was rather slow.

It would appear that the major concern in regard to this compound is the effect on suspended solids concentration in the effluent. The same conclusion was reached based on the values of the supernatant suspended solids recorded periodically during the operation of a batch activated sludge pilot plant receiving this compound. Unfortunately during this period, as with the entire investigational period, the allotted budget and the heavy routine experimental load did not permit close observation of ecological changes taking place in the sludge during the experimental period. Periodic microscopic examinations revealed filaments in the test unit and the control unit throughout the period, and in general when suspended solids concentration was higher in the test unit it appeared to be so because of the noticeably decreased protozoan population in the presence of the test compound.

Methylene Chloride, $\mu_n = 0.2 \text{ day}^{-1}$

Results for the pilot plant which received varying dosages of methylene chloride are shown in Figure 95 and accompanying statistical analyses for this unit and for the control unit during the same period are shown in Table 24. In comparing the behavior of the control unit and the test unit it can be seen that prior to introducing the test compound, both units exhibited rather high effluent suspended solids. However, the suspended solids concentration decreased to acceptable levels in the control but remained extremely high in the test unit throughout the dosages with 5, 25 and 50 mg/l methylene chloride. Cyclical dosing with methylene chloride did not appear to cause the system any more stress than steady dosing at 50 mg/l nor did the resting periods appear to help the system recover. The only noticeable effect during cycling between $25 \longrightarrow 0 \longrightarrow 25$ mg/l was the increase in mixed liquor suspended solids. Much further study would be required in order to provide a more scientifically satisfactory and informative assessment of the effect of cyclical loading of this compound compared to a "steady diet" of the compound. Pulsating loading on the one hand causes a continual state of shock loading and on the other hand can permit rest periods which may benefit the activated sludge. Much more study of this aspect is warranted because results of research studies can be important in making regulatory decisions and recommendations to industries containing such waste compounds in regard to modes of their admission to a publicly owned sewerage system. The highest concentration of methylene chloride observed in the effluent was 0.4 mg/l and this occurred during dosage at 5 mg/l.

Figure 96 shows that methylene chloride is stripped rather rapidly under conditions of this experimentation. Figure 97 shows the results of batch experimentation using sludge from the activated sludge unit after it had been acclimated for more than one month at the 25 mg/l feed level. It is seen that there is very little difference between the undosed system and the systems

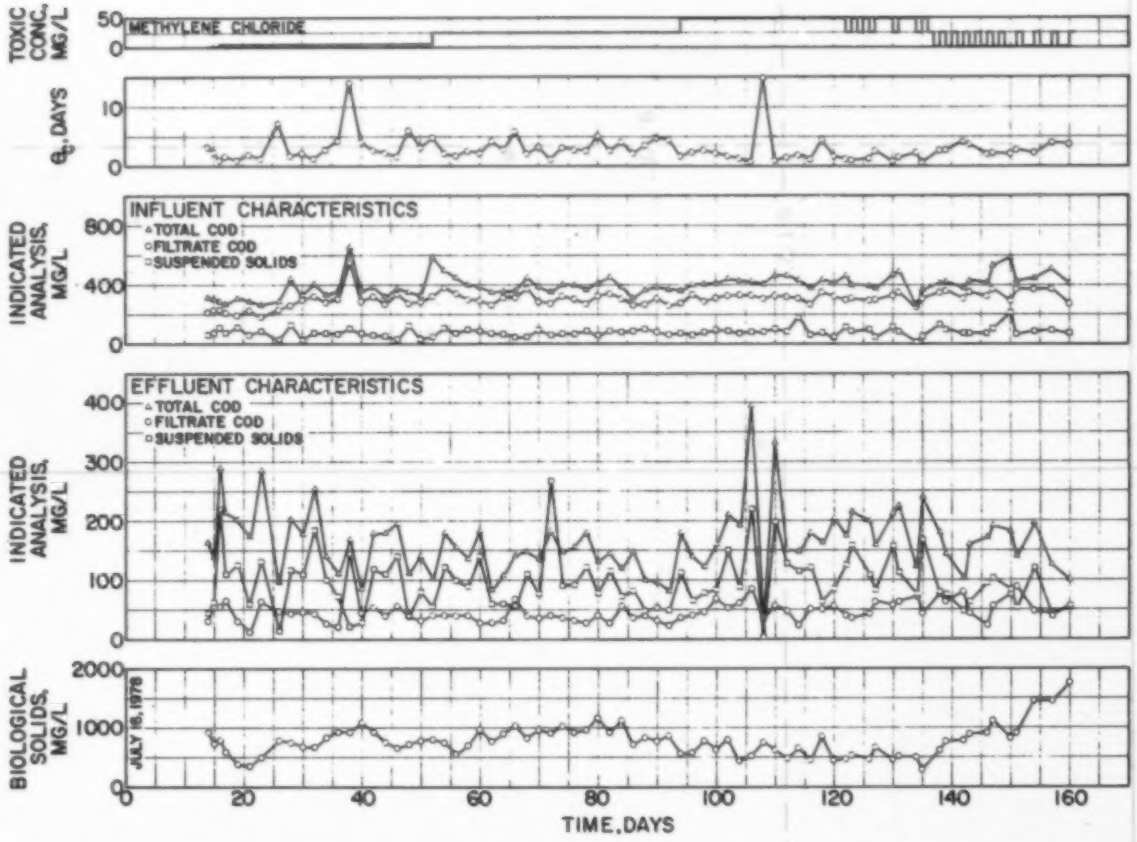

Figure 95. Operational results of continuous flow methylene chloride unit (θ_c=5 days).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-79)

TABLE 24. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH METHYLENE CHLORIDE

Date	Parameter	CONTROL							METHYLENE CHLORIDE							Remarks
		FEED				EFFLUENT			FEED				EFFLUENT			
			COD			COD				COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
7/31/78 to 8/1/78	N	1	1	1	1	1	1	0	3	3	3	3	3	3	3	No toxic compound added.
	X	24	330	282	372	80	44	-	82.3	304	226	818.3	198.0	48.0	109.3	
	σ	-	-	-	-	-	-	-	25.4	14.4	8.7	100.5	80.6	13.9	96.3	
	C.V.	-	-	-	-	-	-	-	30.9	4.7	3.8	12.3	40.7	28.0	88.1	
	Range	-	-	-	-	-	-	-	60 - 110	288 - 316	216 - 232	735 - 930	140 - 290	32 - 56	45 - 220	
8/2/78 to 9/6/78	N	18	18	18	18	16	17	17	18	18	18	19	19	19	19	5 mg/l toxic compound added.
	X	37.8	350.6	282.8	621.3	72.1	40.1	26.1	67.7	368.2	287.5	749.0	162.1	47.0	85.4	
	σ	24.0	94.6	66.9	177.2	44.0	14.2	32.0	31.0	104.8	80.4	197.3	60.4	27.2	49.1	
	C.V.%	63.5	27.0	23.7	28.5	61.1	35.3	122.4	45.8	28	28	26.3	37.3	57.9	57.5	
	Range	0 - 72	249 - 657	229 - 516	336 - 984	32 - 193	12 - 72	0 - 102	24 - 125	264 - 657	184 - 552	387 - 1095	44 - 286	12 - 145	4 - 185	
9/7/78 to 10/18/78	N	21	21	21	21	21	21	21	21	21	21	21	21	21	20	25 mg/l toxic compound added.
	X	39.2	338.1	276.6	764.6	59.2	36.2	23.3	75.9	390.4	304.3	872.2	142.8	37.1	96.7	
	σ	19.7	38.7	40.0	174.0	44.7	10.8	42.6	16.5	42.8	34.3	162.3	34.6	9.9	48.2	
	C.V.%	50.3	11.5	14.4	22.8	75.5	30.0	182.6	21.7	11.0	11.3	18.6	24.2	26.7	49.8	
	Range	0 - 76	240 - 396	212 - 352	444 - 1048	28 - 212	20 - 52	0 - 140	47 - 107	312 - 496	260 - 390	555 - 1170	82 - 196	24 - 68	48 - 267	
10/19/78 to 11/15/78	N	13	13	13	14	12	12	14	14	14	14	14	14	14	14	50 mg/l toxic compound added.
	X	45.8	316.3	254.8	718.3	66.2	39.4	24.5	86.7	425.2	34.9	615.4	188.5	51.4	108.6	
	σ	21.7	31.9	41.2	140.9	53.1	17.0	57.4	31.9	25.0	19.4	138.7	89.8	15.0	55.9	
	C.V.%	47.4	10.1	16.2	19.6	80.2	43.0	234.2	36.8	5.9	6.2	22.5	48	29	51	
	Range	8 - 84	264 - 375	154 - 320	472 - 936	23 - 190	19 - 84	0 - 210	43 - 180	380 - 464	288 - 348	440 - 850	39 - 411	24 - 85	3 - 220	
11/16/78 to 12/23/78	N	19	19	18	19	18	19	19	18	18	18	17	18	18	18	Cyclic changes.
	X	52.8	356.2	265.7	808.6	62.0	40.0	21.8	86.1	429.4	327.9	824.4	170.8	57.4	93.1	
	σ	25.0	66.0	35.5	190.3	45.0	23.6	30.3	41.0	71.2	36.8	409.0	41.6	16.9	38.5	
	C.V.%	47.3	18.5	13.4	23.5	72.6	59.0	138.9	47.7	16.6	11.2	49.6	24.3	29.4	41.4	
	Range	16 - 104	245 - 526	219 - 334	412 - 1132	12 - 162	12 - 76	0 - 100	10 - 210	263 - 584	253 - 376	295 - 1770	100 - 240	24 - 88	40 - 167	

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
9-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.) (4-76)

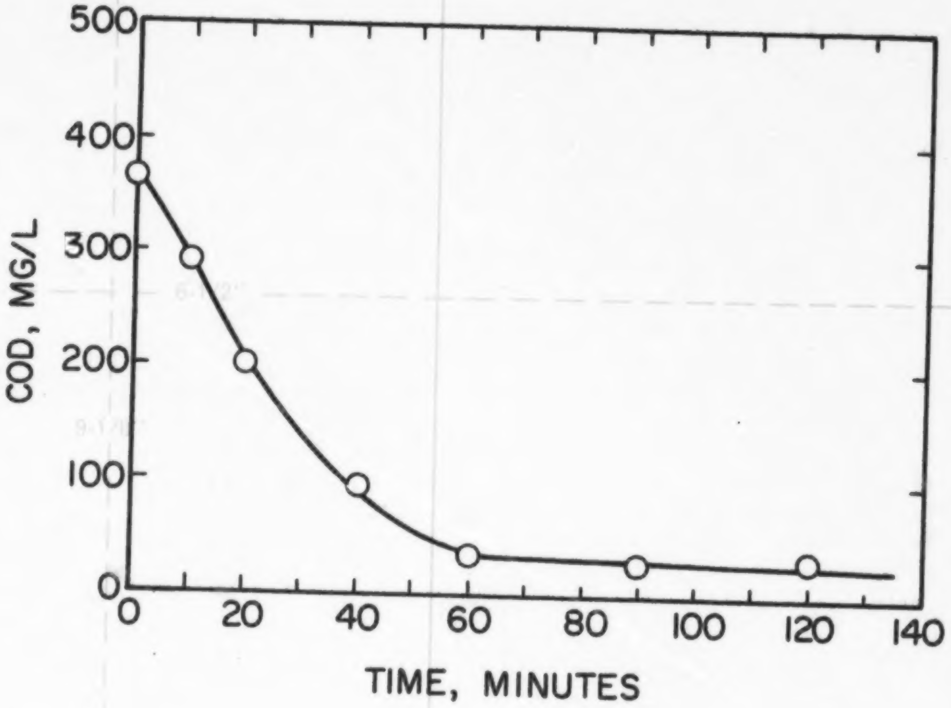

Figure 96. Batch stripping study of methylene chloride in a continuous flow reactor.

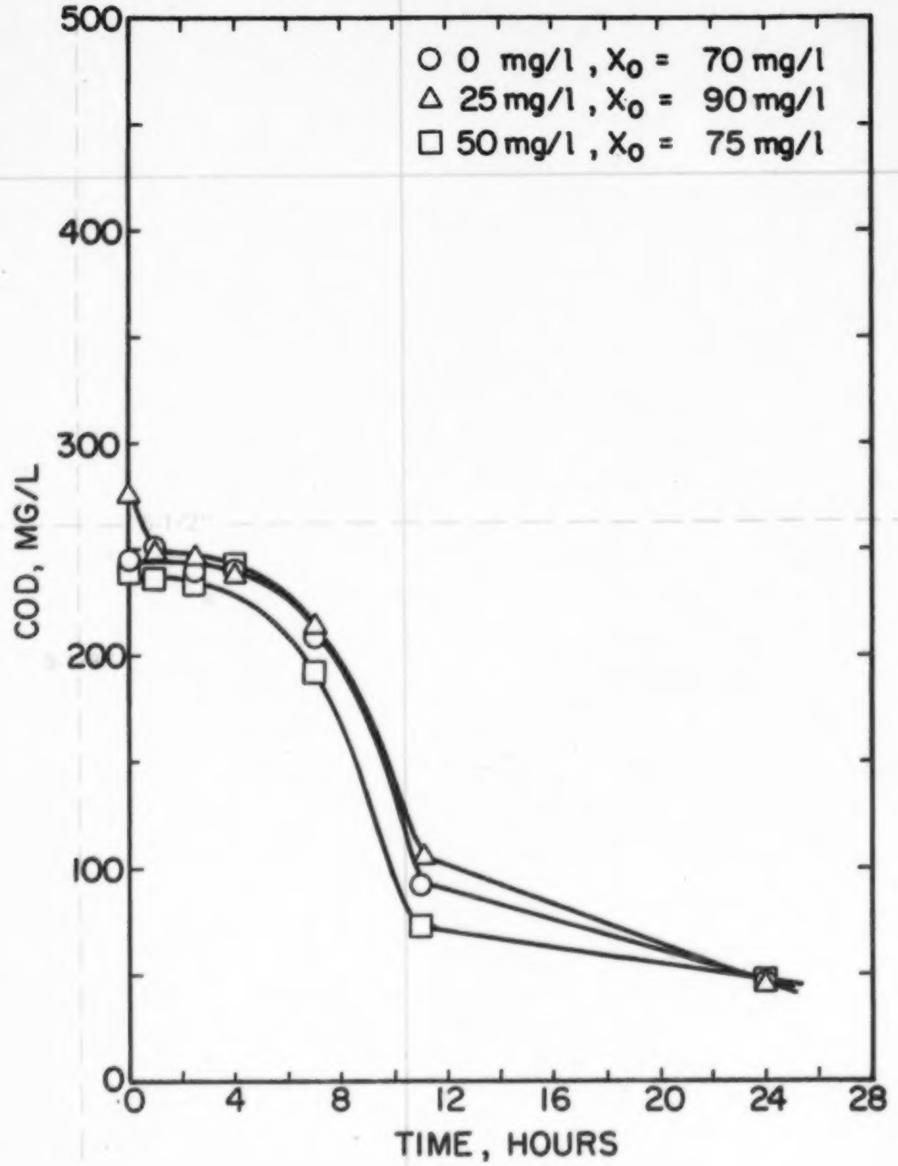

Figure 97. COD removal of continuous flow methylene chloride unit (θ_c = 5 days), dosage=25 mg/1.

which contained 25 and 50 mg/l feed level. It is seen that there is very little difference between the undosed system and the systems which contained 25 and 50 mg/l methylene chloride.

It is interesting to note that when one compares the findings of this study using continuously fed activated sludge with the behavior of the batch activated sludge system which was fed methylene chloride, the conclusions in regard to the possible effects of this compound on the suspended solids in the effluent would be somewhat different. Suspended solids in the supernatant after one hour of settling in the batch pilot plant were lower than effluent suspended solids in the continuous flow pilot plant. However, it can be seen from Figure 95 that when the "no-dosed" period of the pulsing loading was elongated, the mixed liquor solids concentration in the unit tended to increase and the suspended solids concentration may have been entering a decreasing trend. Thus, the longer resting period may have been beneficial to the system. In the batch pilot plant the clearer supernatant may have been related to the fact that a batch-fed system in which the test compound is being removed rapidly does have a resting period between feedings. Much more study using various sludges, with detailed investigation into the sludge ecology, would be needed in order to make definite conclusions and to gain the type of information needed for making general guidelines. It is important to note that the results of these studies, while providing definite indication of compounds which bear close watching and regulatory concern, also provide justification and need for more detailed, concentrated and penetrating fundamental research investigations as to causation.

Whereas results with trichloroethylene provided some indication that pulse loadings with low concentrations of the test compound could be more deleterious than a steadily applied higher load, the results with methylene chloride provide some indication for the reverse effect.

Methylene Chloride, Extended Aeration

The performance of the continuous flow unit which was operated as an extended aeration activated sludge system is shown in Figure 98 and statistical analyses of these results are given in Table 25. Comparison of the results shown in this figure for the extended aeration system with those of Figure 95 for the faster growing system demonstrate, quite strikingly, the better overall effluent quality of the extended aeration system and the fact that the better quality effluent was due to its lower suspended solids concentrations.

Periodic microscopic examinations of both sludges indicated that the extended aeration sludge was much more flocculant and contained fewer filaments and a greater number of protozoa than the faster growing sludge. During the period when the load was pulsed 50 → 25 → 50 mg/l or 25 → 0 → 25 mg/l, there was a slight increase in soluble COD in the effluent but little or no change in effluent suspended solids concentration. There was a rather significant increase in mixed liquor suspended solids during the period of pulsating loading. The same general effect on mixed liquor suspended solids was observed in the faster growing system (see Figure 95). This

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

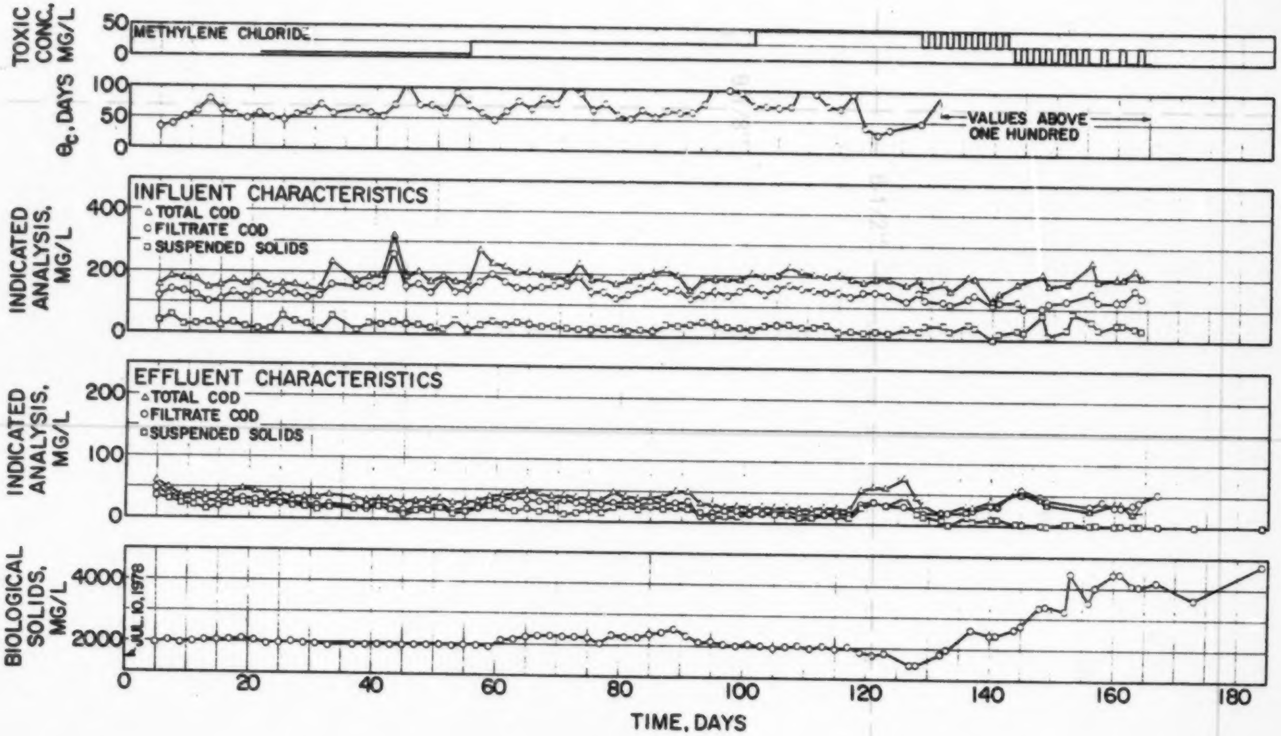

Figure 98. Operational results of continuous flow methylene chloride unit (extended aeration).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(1-70)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM IMAGE AREA OUTSIDE DIMENSIONS FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 25. STATISTICAL ANALYSIS OF DATA FOR AN EXTENDED AERATION PROCESS DOSED WITH METHYLENE CHLORIDE

Date	Parameter	METHYLENE CHLORIDE							Remarks
		FEED			MLSS	EFFLUENT			
			COD			COD			
		S.S.	Total	Fil.		Total	Fil.	S.S.	
7/1/78 to 7/31/78	N	16	16	16	16	16	16	16	No toxic compound added.
	X	50.4	345.1	262.1	2008.8	45.1	34.9	25.8	
		26.2	26.2	24.6	64.9	7.9	7.4	6.5	
	C.V.%	52.1	7.6	9.4	3.2	17.5	21.4	25.2	
	Range	12 - 120	300 - 380	212 - 296	1860 - 2100	36 - 62	26 - 52	15 - 40	
8/1/78 to 9/4/78	N	16	16	16	16	16	16	16	5 mg/1 toxic compound added.
	X	66.6	373.1	305.5	1950.0	33.7	21.6	18.4	
		28.8	83.1	65.8	31.0	4.0	4.7	4.2	
	C.V.%	43.6	22.3	21.5	1.6	11.8	21.6	22.9	
	Range	32 - 120	300 - 640	240 - 520	1900 - 2020	28 - 40	15 - 32	10 - 26	
9/5/78 to 10/19/78	N	23	23	23	23	23	23	23	25 mg/1 toxic compound added.
	X	63.8	400.4	308.3	2204.3	39.1	27.9	18.5	
		17.7	51.0	36.2	150.1	7.5	7.1	4.7	
	C.V.%	27.8	12.7	11.7	6.8	19.1	25.6	25.5	
	Range	36 - 96	300 - 552	248 - 396	1900 - 2520	26 - 52	12 - 38	10 - 26	
10/20/78 to 11/15/78	N	13	13	13	14	13	13	13	50 mg/1 toxic compound added.
	X	61.4	397.5	296.5	1812.1	38.3	22.1	20.9	
		18.5	29.9	24.1	318.8	18.5	7.5	10.8	
	C.V.%	30.1	7.5	8.1	17.6	48.3	34.0	51.6	
	Range	36 - 84	346 - 464	244 - 340	960 - 2040	24 - 76	15 - 36	10 - 46	
11/16/78 to 12/21/78	N	19	17	18	17	15	16	19	Cyclic changes
	X	80.6	374.1	254.4	3287.6	34.5	32.1	3.7	
		42.1	60.7	31.6	887.9	11.2	10.0	4.5	
	C.V.%	52.2	16.2	12.4	27.0	32.5	31.1	121.4	
	Range	0 - 176	241 - 500	207 - 332	1810 - 4480	20 - 57	16 - 51	0 - 14	

effect if sustained could be important, particularly in the case of extended aeration, since success of such a process is militated against by build-up of mixed liquor suspended solids. The only analyses run were during the dosage level of 25 mg/l; methylene chloride was not detected at the lowest limit of detection, 0.001 mg/l.

The results of a batch study made using sludge taken from the extended aeration unit after acclimation to 25 mg/l of methylene chloride for approximately one and one-half months are shown in Figure 99. The control system removed the COD at a slightly more rapid rate than did the system which received an initial concentration of either 25 or 50 mg/l of methylene chloride.

The major finding in regard to the operation of the extended aeration plant which received methylene chloride was that the results compared most favorably with those for the faster growing activated sludge system. This finding is consistent with previously presented results in this report. The statistical analyses for the extended aeration plant results shown in Table 25 compare very favorably with the statistical analysis results for the continuous flow activated sludge pilot plant which received no known dosages of priority pollutants (see performance of the control system, Table 24).

Control Unit, $\mu_n = 0.2$ day-1

The operational performance during early 1979 of the activated sludge pilot plant which was not dosed with test compounds is shown in Figure 100. It is seen that the process provided an excellent effluent but that for a period of approximately two weeks in late March, the effluent was not as good as it was prior to and after this period. This slight upset corresponded to a slightly increased total COD in the incoming feed, and in late March there was a sharp decrease in mixed liquor suspended solids concentration. The system recovered rather rapidly, however.

1,2-Dichloroethane, $\mu_n = 0.2$ days^{-1}

The response of an activated sludge system dosed with varying concentrations of 1,2-dichloroethane is shown in Figure 101 and this performance is compared statistically to that in the control over the comparable operating period in Table 26. It can be seen from Figure 101 that the system provided rather good effluent through the period of dosing of 5 mg/l of the text compound although, as noted in Table 26, the performance was not quite as good as that of the control during this period. When the dosage was increased to 25 mg/l, there was a considerable increase in total effluent COD which was caused by the loss of suspended solids. The system recovered but the level of performance did not return to that which was observed when the dosage was 5 mg/l. The effluent quality also continued to deteriorate at the dosage of 50 mg/l.

This compound had been previously shown to be highly strippable under the conditions of this experimentation. Figure 102 shows the results of a

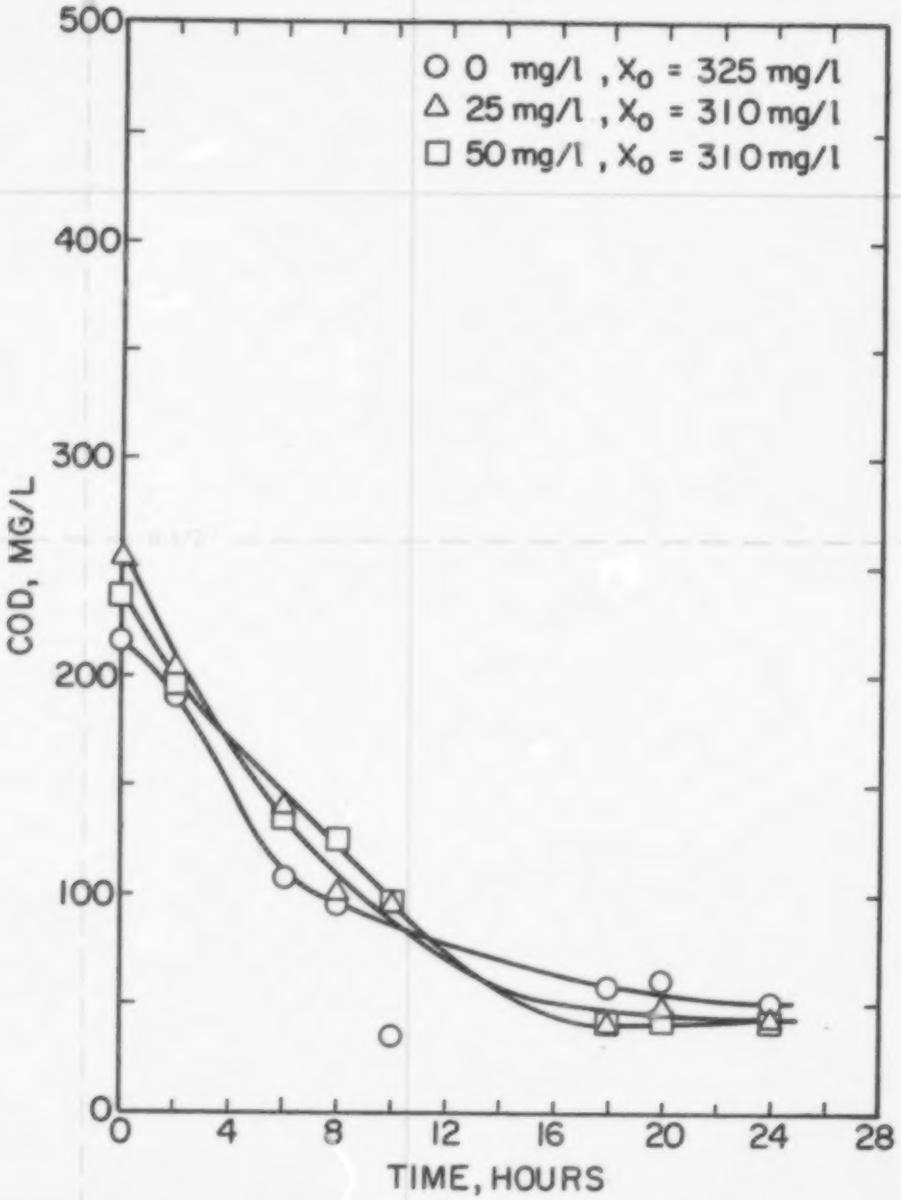

Figure 99. COD removal of continuous flow methylene chloride unit (extended aeration), dosage=25 mg/l.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

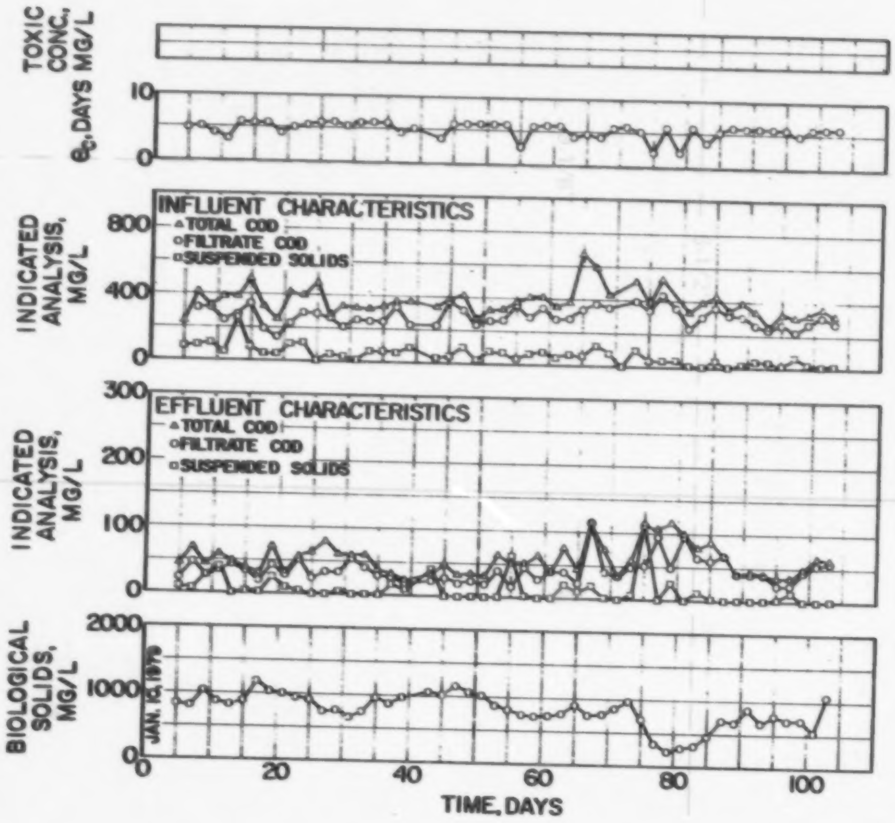

Figure 100. Operational results of continuous flow control (θ_c=5 days), from January 1979.

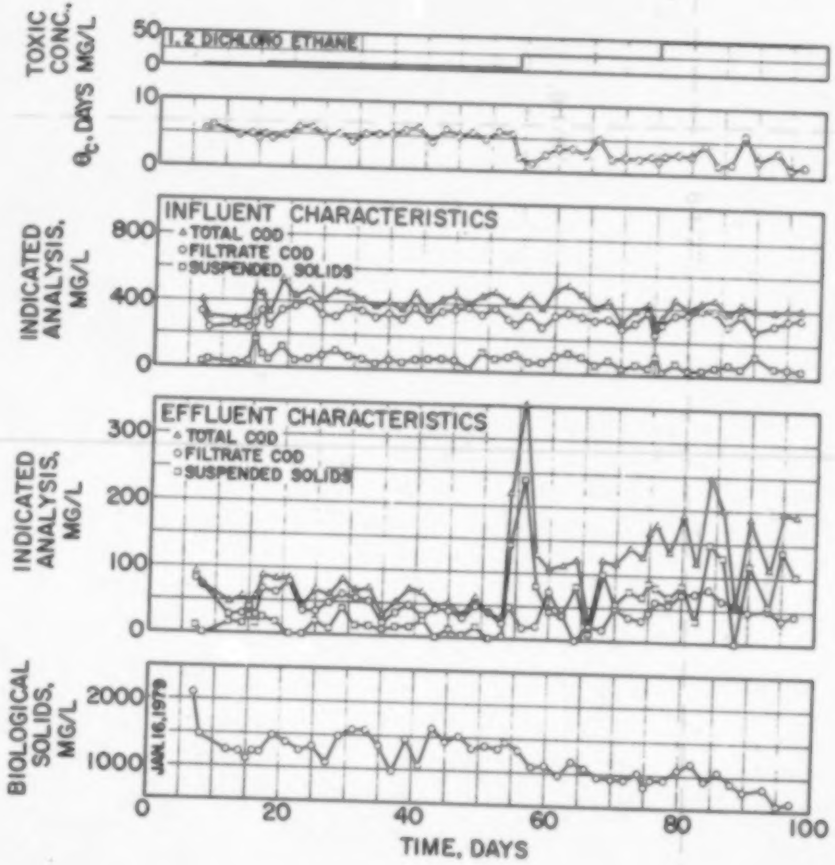

Figure 101. Operational results of continuous flow 1,2-Dichloroethane unit (θ_c=5 days).

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

TABLE 26. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH 1,2,-DICHLOROETHANE

Date	Parameter	CONTROL							1,2-DICHLOROETHANE							Remarks
		FEED				EFFLUENT			FEED				EFFLUENT			
			COD			COD				COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/20/79 to 1/31/79	N	6	6	6	6	6	6	6	7	7	7	7	7	7	7	No toxic compound added.
	X	100.0	379.5	238.7	971.3	47.3	34.7	13.2	72.9	371.4	288.6	1836.7	79.4	62.9	16.0	
	σ	83.6	80.8	68.1	130.6	16.1	9.4	16.1	54.8	83.8	49.6	760.1	34.6	34.4	8.7	
	C.V.%	83.6	21.3	28.6	13.4	34.0	27.0	122.1	75.2	22.6	17.2	41.4	43.6	54.6	54.6	
	Range	48 - 264	258 - 500	145 - 342	836 - 1188	32 - 72	20 - 44	0 - 40	30 - 170	292 - 500	236 - 352	1215 - 2925	48 - 144	28 - 124	0 - 25	
2/1/79 to 3/11/79	N	18	18	18	18	18	18	18	21	21	21	21	21	21	21	5 mg/1 toxic compound added.
	X	59.1	363.1	282.9	896.4	49.6	31.1	7.9	72.5	427.8	341.0	1340.0	67.8	44.9	19.1	
	σ	30.0	50.2	48.9	143.3	15.7	11.3	16.8	27.0	45.7	35.5	163.3	39.1	15.2	29.9	
	C.V.%	50.9	13.8	17.3	16.0	31.6	36.3	213.0	37.2	10.7	10.3	12.2	57.6	33.8	156.3	
	Range	4 - 116	276 - 475	216 - 380	664 - 1156	23 - 81	16 - 54	0 - 62	18 - 128	336 - 530	256 - 400	975 - 1615	32 - 220	20 - 80	0 - 142	
3/12/79 to 4/1/79	N	10	8	9	10	10	10	10	11	11	11	11	11	11	11	25 mg/1 toxic compound added.
	X	63.2	488.5	352.7	704.8	78.8	54.0	19.9	69.2	421.9	320.4	1034.0	138.0	31.6	79.4	
	σ	35.9	113.4	49.9	232.6	33.2	28.9	33.7	30.7	69.3	40.6	144.1	78.2	19.6	59.2	
	C.V.%	56.7	23.2	14.1	33.0	42.1	53.4	169.3	44.4	16.4	12.7	13.9	56.7	61.9	74.6	
	Range	0 - 124	360 - 680	280 - 437	240 - 944	36 - 116	24 - 116	0 - 112	20 - 120	312 - 528	244 - 378	810 - 1335	29 - 352	0 - 72	10 - 240	
4/2/79	N	12	12	12	12	12	12	12	11	11	11	11	11	11	11	50 mg/1 toxic compound added.
	X	28.7	346.0	282.6	649.3	59.0	51.0	2.3	54.1	409.6	342.4	891.3	165.1	58.4	87.2	
	σ	19.8	48.4	40.4	226.1	21.8	20.2	4.6	28.1	33.4	38.1	183.8	53.1	13.5	45.9	
	C.V.%	69.1	14.0	14.3	34.8	36.9	39.6	196.2	52.0	8.2	11.3	20.6	32.2	23.1	52.7	
	Range	0 - 72	248 - 436	225 - 360	292 - 1088	36 - 100	24 - 96	0 - 12	20 - 125	344 - 456	278 - 396	585 - 1180	58 - 248	36 - 80	0 148	

EPA-287 (Cin.)
(4-76)

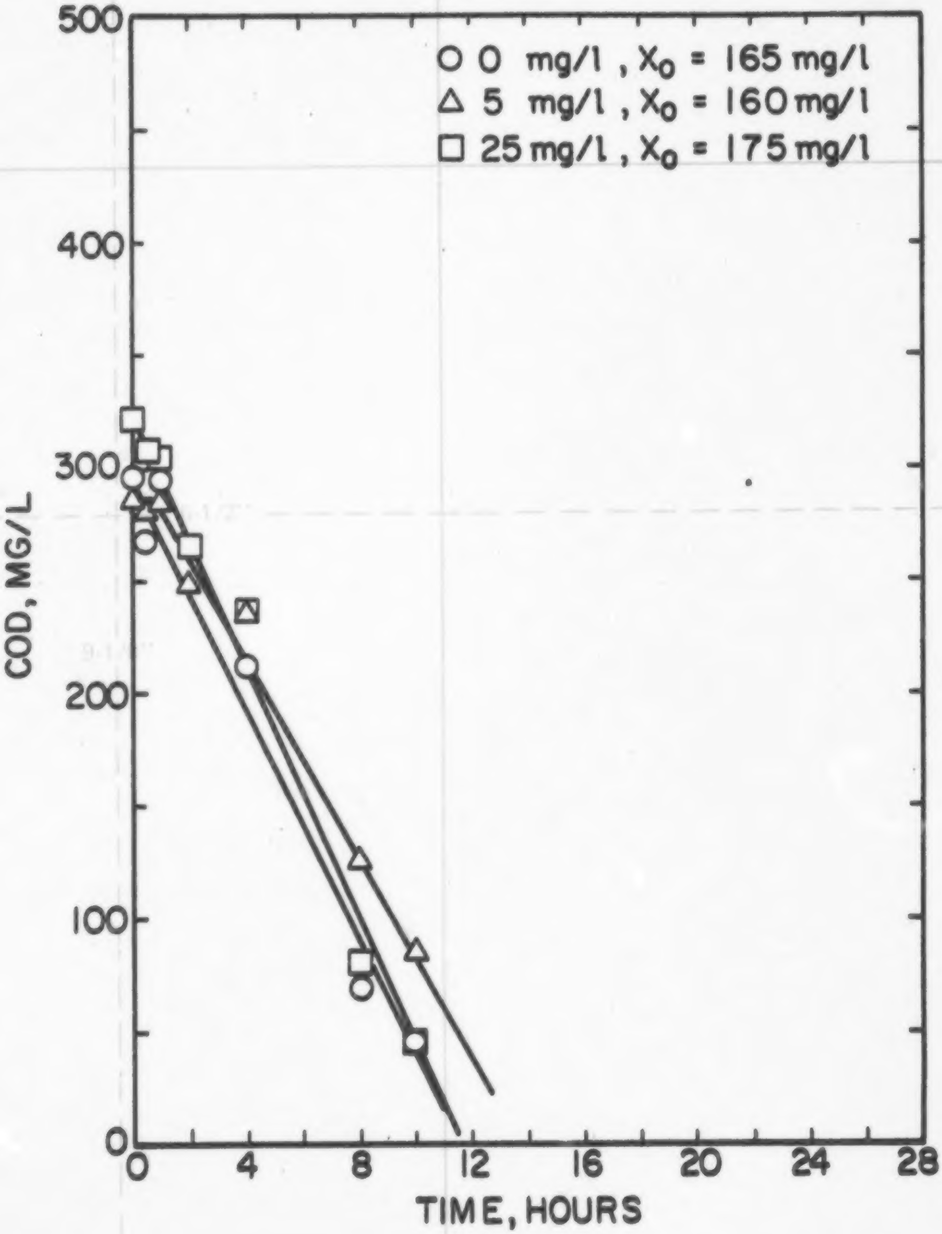

Figure 102. COD removal of continuous flow 1,2-Dichloroethane unit (θ_c=5 days), dosage=5 mg/l.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

batch study using sludge from the pilot plant after it had been receiving a dosage of 5 mg/l of the test compound for approximately one month. It is seen that from the standpoint of substrate removal, increasing the dosage from 5 to 25 mg/l did not cause a biochemical stress. However, it is seen by comparing these results with those in the continuous flow unit on the same day that the effect was to cause interference with flocculating ability and settling. Results such as these provide additional evidence of the wisdom of further study of the effect of priority pollutants on sludge ecology as it is related to settleability and turbidity of an effluent.

4-Chloro, 3-Methyl Phenol, $\mu_n = 0.2$ days^{-1}

The response of a continuous flow activated sludge pilot plant to varying dosages of 4-chloro,3-methyl phenol is shown in Figure 103 and comparative statistical data on the performance shown in this figure with performance over the comparable time period for the control is shown in Table 27. It is seen that the performance of the test unit compares favorably with that of the control for dosages of test compound of 5 and 25 mg/l. When the dosage was changed from 5 to 25 mg/l there was a short-lived increase in filtrate COD. However, the system rapidly recovered. There was considerably greater upset when the dosage was increased from 25 to 50 mg/l. The COD leakage was associated primarily with leakage of soluble COD in the effluent rather than COD due to effluent suspended solids. It is not known whether the high suspended solids values recorded on the last day of this experimentation represent a worsening oscillation of suspended solids levels due to the dosage of 50 mg/l of test compound since it was necessary to terminate the experiments in order to meet the reporting deadlines for the investigation. However, it is clear from the experimental data that the addition of this test compound at the concentrations studied herein can cause temporary, if not long-lived, disturbance of effluent quality. Previous studies during operation of the batch pilot plants had shown that the test compound was not strippable under the conditions of these experimentations. Figure 104 shows the results of a batch growth substrate removal study made after the unit had been receiving a dosage of 25 mg/l of 4-chloro,3-methyl phenol for a period of three weeks. It is seen that substrate removal in the control was slightly more rapid than in either of the test units. This result provides some indication that even though this sludge was acclimated to the test compound for three weeks, the cessation of dosage could cause faster substrate removal. The results of other batch studies made during this continuous-flow pilot plant operation tend to substantiate the above conclusion.

4-Chloro,3-Methyl Phenol, Extended Aeration

The performance of an extended aeration process dosed with varying concentrations of 4-chloro,3 methyl phenol is shown in Figure 105 and statistical analyses of these data are presented in Table 28. It is clear from comparison of Figure 105 with the performance of the faster growing system (see Figure 103) that at 5 and 25 mg/l dosage of the test compound the extended aeration system provided much better effluent. In fact, the results for the extended aeration system compare extremely well with those for the

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

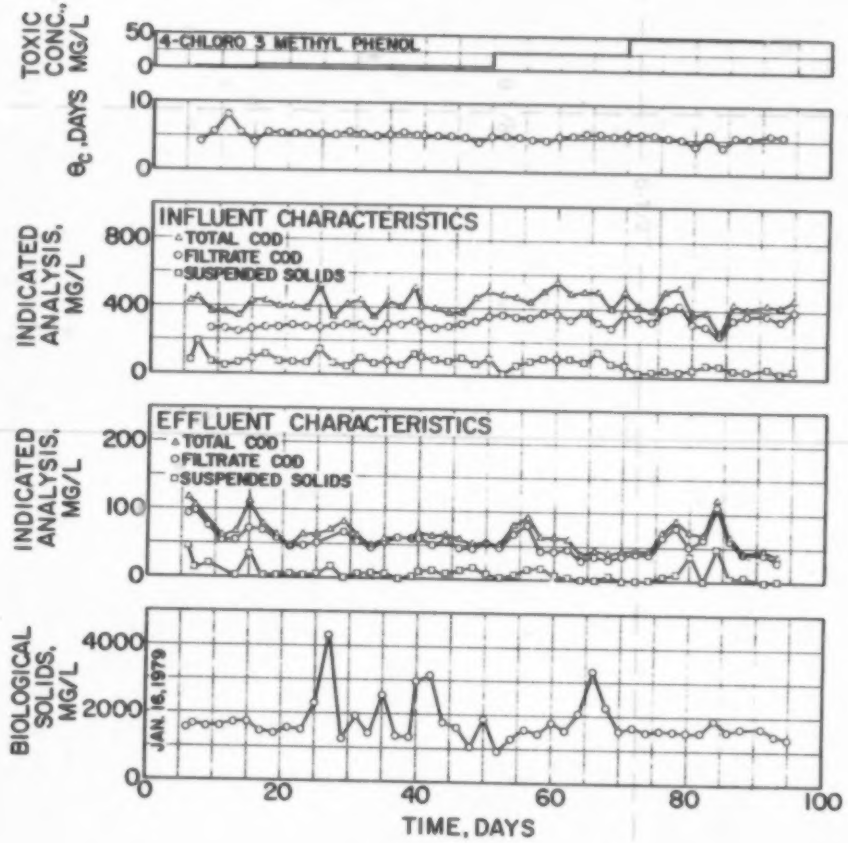

Figure 103. Operational results of continuous flow 4-chloro, 3-methyl phenol unit (θ_c=5 days).

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 27. STATISTICAL COMPARISON OF OPERATIONAL DATA FOR AN UNDOSED CONTROL ACTIVATED SLUDGE PROCESS AND ONE DOSED WITH 4-CHLORO, 3-METHYL PHENOL

Date	Parameter	CONTROL							4-CHLORO, 3-METHYL PHENOL							Remarks
		FEED				EFFLUENT				FEED			EFFLUENT			
			COD			COD				COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/22/79 to 1/31/79	N	5	5	5	5	5	5	5	6	7	4	6	5	6	5	No toxic compound added.
	X	108.8	378.8	237.4	988.8	44.8	34.4	7.8	93.3	401.2	262.0	1635.8	93.0	75.3	23.4	
	σ	90.3	90.4	76.1	137.9	16.6	10.4	10.4	51.5	44.2	9.6	64.2	26.5	18.2	16.7	
	C.V.%	83.0	23.9	32.1	13.9	37.0	30.3	132.7	55.2	11.0	3.6	3.9	28.5	24.2	71.4	
	Range	48 - 264	258 - 500	145 - 342	836 - 1188	32 - 72	20 - 44	0 - 25	50 - 195	348 - 453	248 - 269	1550 - 1710	61 - 118	55 - 98	3 - 45	
2/1/79 to 3/8/79	N	17	17	17	17	17	17	17	18	18	18	17	17	17	18	5 mg/l toxic compound added.
	X	57.8	360.2	279.1	906.8	48.8	31.2	8.4	90.9	421.2	295.0	1848.7	62.3	55.2	7.6	
	σ	30.5	50.2	47.6	140.6	15.7	11.6	17.2	25.7	53.5	19.9	598.7	9.5	7.6	5.3	
	C.V.%	52.7	13.9	17.0	15.5	32.3	37.2	206.0	28.3	12.7	6.7	32.3	15.3	13.7	69.4	
	Range	4 - 116	276 - 475	216 - 380	664 - 1156	23 - 81	16 - 54	0 - 62	52 - 150	342 - 528	257 - 348	1048 - 3124	47 - 84	45 - 71	0 - 18	
3/9/79 to 3/28/79	N	10	9	9	10	10	10	10	10	10	10	10	10	10	10	25 mg/l toxic compound added.
	X	66.4	480 0	351.7	752.8	73.6	52.0	17.4	89.0	484.4	350.4	1780.6	57.9	46.2	6.0	
	σ	35.8	109.1	49.9	166.1	30.7	30.0	34.2	33.8	39.2	28.8	655.0	17.7	16.0	6.0	
	C.V.%	53.9	22.7	14.2	22.1	41.7	57.7	196.6	38.0	8.1	8.2	36.8	30.6	34.7	100.0	
	Range	0 - 124	360 - 690	280 - 437	344 - 900	36 - 116	28 - 116	0 - 112	18 - 148	408 - 552	290 - 380	916 - 3308	39 - 92	30 - 80	0 - 17	
3/29/80 to 4/23/79	N	13	12	13	13	13	13	13	12	12	12	12	12	12	12	50 mg/l toxic compound added.
	X	30.2	346.0	288.3	617.8	63.4	50.8	4.1	47.3	420.0	349.9	1549.9	88.4	56.8	26.9	
	σ	19.7	48.4	43.9	244.5	26.2	19.4	7.7	15.8	68.1	46.8	159.2	88.7	22.3	58.5	
	C.V.%	65.3	14.0	15.2	39.6	41.3	38.1	188.0	33.4	16.2	13.4	10.3	100.4	39.3	217.4	
	Range	0 - 72	248 - 436	225 - 360	240 - 1088	36 - 116	24 - 96	0 - 25	28 - 76	264 - 530	252 - 423	1372 - 1896	38 - 360	30 - 112	0 - 206	

BEGIN LAST LINE OF TEXT

3/8"

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

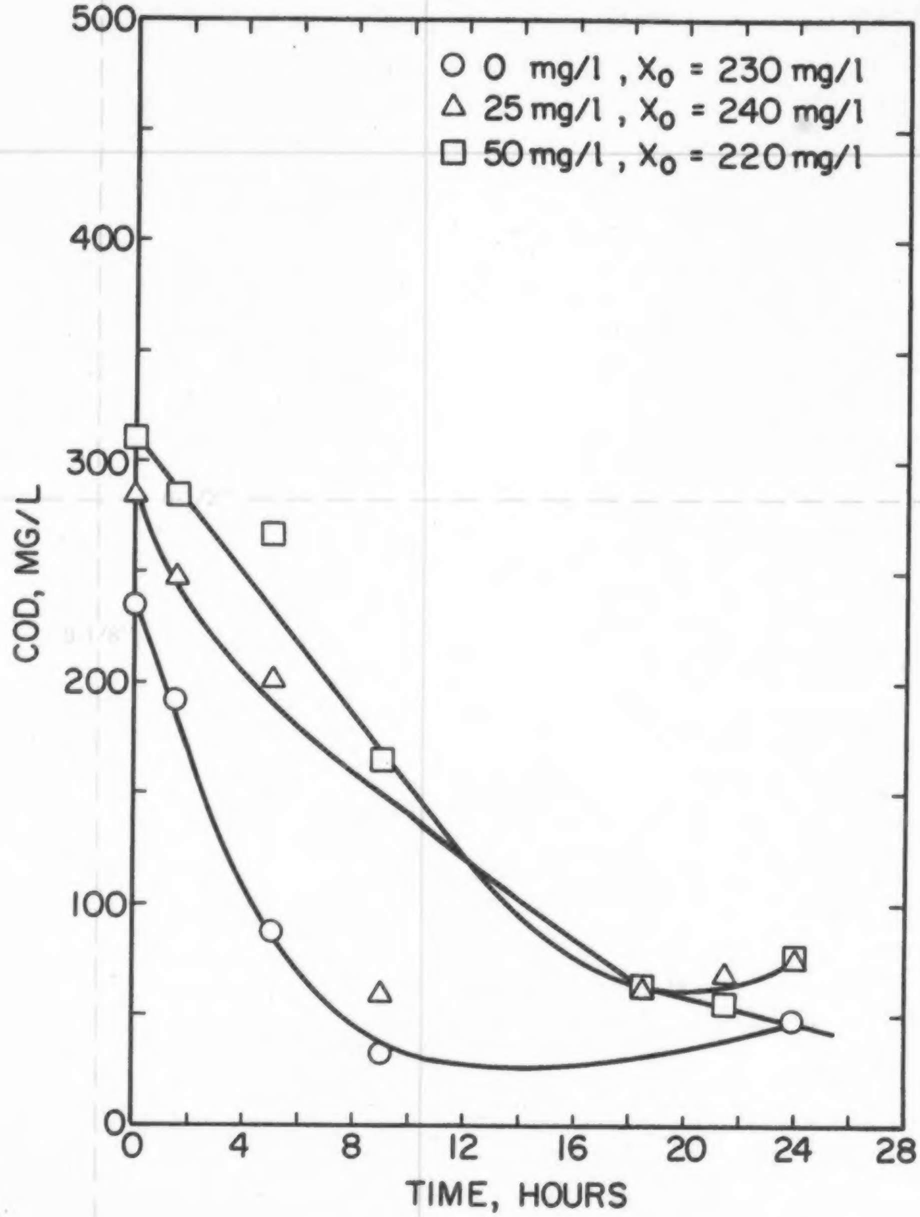

Figure 104. COD removal of continuous flow 4-chloro, 3-methyl phenol unit (θ_c=5 days), dosage=25 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

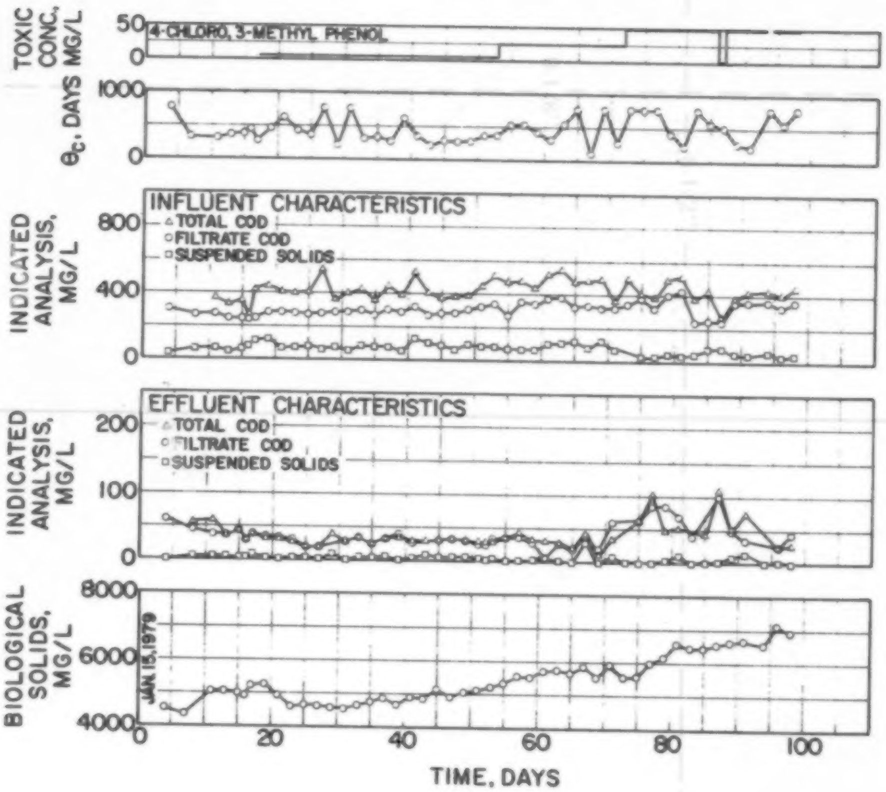

Figure 105. Operational results of continuous flow 4-chloro, 3-methyl phenol unit (extended aeration).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 28. ANALYSIS OF DATA FOR EXTENDED AERATION PROCESS DOSED WITH 4-CHLORO, 3-METHYL PHENOL

Date	Parameter	4 CHLORO, 3-METHYL-PHENOL							Remarks
		FEED			EFFLUENT				
			COD			COD			
		S.S.	Total	Fil.	MLSS	Total	Fil.	S.S.	
1/19/79 to 1/31/79	N	6	4	6	6	5	6	6	No toxic compound added.
	X	61.3	335.7	265.2	4816.2	45.0	42.0	3.8	
	σ	16.9	46.0	25.5	288.5	13.2	11.1	2.1	
	C.V.%	27.6	13.7	9.6	6.0	29.3	26.5	55.7	
	Range	36 - 84	272 - 379	240 - 306	4370 - 5047	28 - 59	28 - 61	0 - 6	
2/1/79 to 3/8/79	N	18	18	18	18	18	13	18	5 mg/1 toxic compound
	X	86.6	420.6	289.6	4843.6	31.0	31.5	4.9	
	σ	22.3	49.7	18.4	236.1	5.5	5.6	3.1	
	C.V.%	25.8	11.8	6.3	4.9	17.9	17.7	63.4	
	Range	56 - 134	360 - 544	252 - 324	4530 - 5247	20 - 40	20 - 40	0 - 10	
3/9/79 to 3/27/79	N	10	10	10	10	10	9	9	25 mg/1 toxic compound added.
	X	92.7	481.6	337.5	5618.4	31.6	30.6	3.4	
	σ	20.7	51.9	32.0	219.6	9.6	17.3	3.1	
	C.V.%	22.4	10.8	9.5	3.9	30.2	56.7	89.6	
	Range	72 - 124	364 - 556	272 - 385	522 - 5930	12 - 44	6 - 40	0 - 9	
3/28/79 to 4/23/79	N	12	13	13	13	9	9	12	50 mg/1 toxic compound added.
	X	49.7	422.9	338.6	6407.0	60.1	58.8	3.9	
	σ	16.7	62.8	59.8	468.8	30.5	26.7	5.1	
	C.V.%	33.6	14.9	17.6	7.3	50.7	45.4	130.8	
	Range	32 - 80	272 - 512	240 - 429	5551 - 7150	26 - 112	24 - 100	0 - 14	

undosed control system during this same period of time (Figure 100). The COD in the effluent increased during the 50 mg/l dosage level; the increase was due primarily to an increase in soluble COD. Since the same tendency was noted in the control system during this period of operation, it is difficult to say whether the increase in soluble COD in the extended aeration pilot plant effluent was due to the increased dosage of the test compound or was a natural consequence of some unknown constituent introduced with the municipal sewage. In any event it is clear that prior to this occurrence the extended aeration process showed a much greater ability to handle the test compound at significantly high dosage levels, i.e., 5 and 25 mg/l.

Batch studies made using sample of this activated sludge when the dosage level was changed from 0 to 5 mg/l and 5 to 25 mg/l showed little or no difference between the behavior of an undosed control and systems receiving 5 and 25 mg/l of the test compound. However, when a batch study was made at the time the extended aeration pilot plant dosage was changed from 25 to 50 mg/l there was considerable difference in substrate removal rate between the undosed control and the systems receiving 25 and 50 mg/l as can be seen from the results shown in Figure 106. Thus, it would appear that a sludge such as this one which had been providing good indication that it was acclimated to 25 mg/l dosage was capable of removing substrate significantly more rapidly when that dosage was withheld.

SUMMARY OF DATA

The data for all of the pilot plant studies are summarized in Table 29. For batch studies, the criterion of performance in the presence of the priority pollutant is removal of COD, i.e., metabolic efficiency. For the continuous flow pilot plants, those operated at $\mu_n = 0.2$ day^{-1} ($\Theta = 5$ days) and those operated as extended aeration processes, S_e and X_e, i.e., COD and suspended solids concentrations in the effluent, are presented. It is apparent from the data for the pilot plants exposed to the same compounds over the same range of concentrations, but under different operational conditions, that the batch mode of operation is not a reliable method for detecting possible deleterious effects of priority pollutants upon biological treatment processes. It is also apparent that the extended aeration process provided better effluent than did the comparable faster growing systems in the presence of the same concentrations of the priority pollutants.

FATE OF TEST COMPOUNDS

The results of the analyses made for the specific test compounds is given in Table 30. It is seen that when the analysis of the feed samples are compared with the dosage level there is a high level of recovery. This shows that the desired dosage level was present in the influents to the various treatment processes.

Table 30 also shows that in most cases the specific compounds were

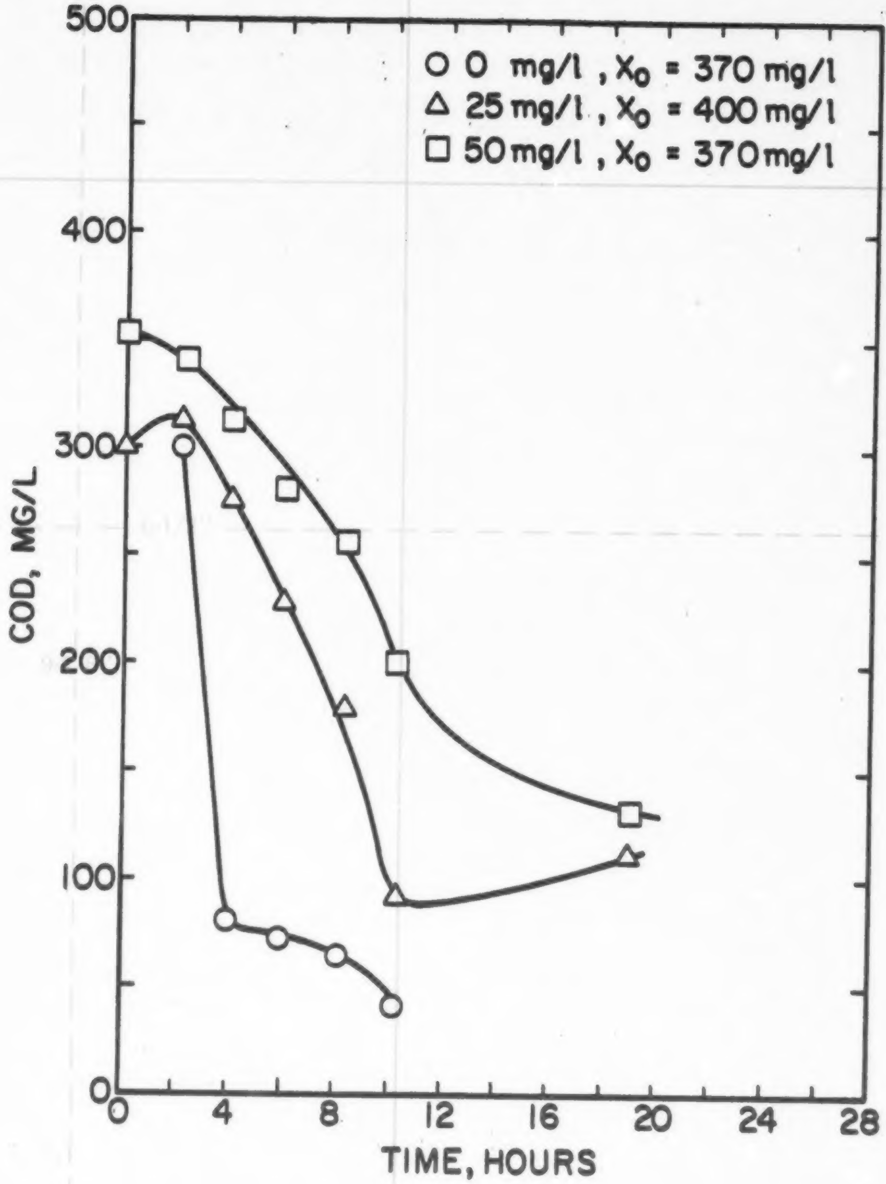

Figure 106. COD removal of continuous flow 4-chloro, 3-methyl phenol unit (extended aeration) dosage=25 mg/l.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 29. SUMMARY OF EFFECTS OF PRIORITY POLLUTANTS

Compound	Parameter	Batch Unit Dosage					Continuous Flow									
							$\mu_n = 0.2\ \text{day}^{-1}$ Dosage					Extended Aeration Dosage				
		0	5	25	50	Cyclic	0	5	25	50	Cyclic	0	5	25	50	Cyclic
Naphthalene	S_e	0	0	0*	0	0										
	X_e															
Toluene	S_e	0	0	0*	0	0										
	X_e															
Hexachloro-benzene	S_e	0	0	0	0	0										
	X_e															
Benzene	S_e	0	0	0*	0	0	0	0	0*	0	0					
	X_e						0	0	0*	0	0	0	X	X*	X	X
Phenol	S_e	0	0	0*	0	0	0	0	X*	X	X	0	0	0*	X	X
	X_e						0	X	X*	X	X					

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
9 1/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 29. (continued)

Compound	Parameter	Batch Unit Dosage					Continuous Flow $\mu_n = 0.2$ day^{-1} Dosage					Continuous Flow Extended Aeration Dosage				
		0	5	25	50	Cyclic	0	5	25	50	Cyclic	0	5	25	50	Cyclic
Trichloro ethylene	S_e	0	0	0	0	0	0	0	0	0	X					
	X_e						0	0	0	0	X					
Chlorobenzene	S_e	0	0	0	0	0										
	X_e															
Tetrachloro-ethylene	S_e	0	0	0	0	0										
	X_e															
4-Chloro,3-Methyl Phenol	S_e	0	0	X	X	-	0	0	0	?	-	0	0	0	?	-
	X_e						0	0	0	0	-	0	0	0	0	-
Ethylbenzene	S_e	0	0	0	0	-										
	X_e															

(continued)

EPA-287 (Cin.)
(4-76)

TABLE 29. (continued)

Compound	Parameter	Batch Unit Dosage					Continuous Flow									
							$\mu_n = 0.2\ day^{-1}$ Dosage					Extended Aeration Dosage				
		0	5	25	50	Cyclic	0	5	25	50	Cyclic	0	5	25	50	Cyclic
Fluorene	S_e	0	0	0	0	0										
	X_e															
Hexachloro-ethane	S_e	0	0	0	0	0										
	X_e															
Methylene Chloride	S_e	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	X_e						0	X	X	X	X	0	0	0	0	0
Carbon Tetrachloride	S_e	0	0	0	0	0										
	X_e															
Chloroform	S_e	0	0	0	0	0										
	X_e															

(continued)

TABLE 29. (continued)

Compound	Parameter	Batch Unit Dosage					Continuous Flow									
							μ_n = 0.2 day^{-1} Dosage					Extended Aeration Dosage				
		0	5	25	50	Cyclic	0	5	25	50	Cyclic	0	5	25	50	Cyclic
Pentachloro - phenol	S_e	0	X	X*	X	X										
	X_e															
Nitrobenzene	S_e	0	0	0	0	0	0	0	0*	0	0					
	X_e						0	0	0*	0	X					
2-Chloro-phenol	S_e	0	X	X	X	0	0	0	0*	0	0	0	0	0	0	0
	X_e						0	0	0*	X	X	0	0	0	0	0
Anthracene	S_e	0	0	0	0	0										
	X_e															
2-Nitrophenol	S_e	0	0	0	0	0										
	X_e															

(continued)

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

TABLE 29. (continued)

Compound	Parameter	Batch Unit Dosage					Continuous Flow									
							$n = 0.2$ day^{-1} Dosage					Extended Aeration Dosage				
		0	5	25	50	Cyclic	0	5	25	50	Cyclic	0	5	25	50	Cyclic
1.2-Dichloro-ethane	S_e	0	0	0	0	-	0	0	0	0	-					
	X_e						0	0	X	X	-					
1,1,2-Trichloro-ethane	S_e	0	0	0	0	-										
	X_e															
Bromoform	S_e	0	0	0	0											
	X_e															
Tetrachloro-ethane	S_e	0	0	0	0											
	X_e															

0 Performance same as control.

* Toxic Dosage = 20 mg/1 rather than 25 mg/1.

X Performance poor compared with control.

? Performance poor in both control and test system.

EPA-287 (Cin.)
(4-76)

TABLE 30. SPECIFIC COMPOUND ANALYSIS

Name of Compound	Dosage level mg/1	Concentration of Compound								
		Activated sludge (θ_c=5 days)			Extended aeration			Batch		
		Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent
Naphthalene	0–25 cycle	--	--	--	--	--	--	--	--	0.007
Toluene	--	--	--	--	--	--	--	--	--	--
Hexachlorobenzene	--	--	--	--	--	--	--	--	--	--
Benzene	--	--	--	--	--	--	--	--	--	--
Phenol	20	--	--	0.01	18.1	--	0.007	--	--	0
	50	39.0	0	0.005	--	--	--	--	--	--
	25–50 cycle	--	--	0	--	--	0	--	--	--
Pentachlorophenol	--	--	--	--	--	--	--	--	--	--
Nitrobenzene	5	--	--	--	--	--	--	--	<0.001	2.4
	25	--	--	--	--	--	--	16.0	<0.007	--
	50	--	<0.01	<0.01	--	--	--	23.4	<0.001	<0.001
	0–25 cycle	--	--	--	--	--	--	--	<0.012	<0.012
	0–0–0–25 cycle	--	--	--	--	--	--	6.8	<0.001	<0.07
2-chlorophenol	5	2.4	<0.001	<0.01	3.0	--	--	2.8	0	0
	20–25	12.4	0.02	0.012	--	--	--	18.0	<0.05	--
	50	32.4	--	--	--	--	<0.0032	43.0	<0.012	<0.026

(continued)

TABLE 30. (continued)

Name of Compound	Dosage level mg/1	Concentration of Compound								
		Activated sludge (θ_c=5 days)			Extended aeration			Batch		
		Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent
Anthracene	0-25 cycle	--	--	--	--	< 0.0064	<0.0032	--	--	--
	25-50 cycle	37.8 (50)	--	31.0	--	--	--	--	--	--
	0-0-25 cycle	--	--	--	--	--	--	27.8	7.3	<0.07
	5	--	--	--	--	--	--	2.0	4.6	<0.004
	25	--	--	--	--	--	--	9.6	10.8	<0.002
	50	--	--	--	--	--	--	26.0	39.3	0.12
	0-0-0-25 cycle	--	--	--	--	--	--	13.2 (25)	22.0	0
2-Nitrophenol	5	--	--	--	--	--	--	--	<0.02	<0.02
	25	--	--	--	--	--	--	23.1	<0.04	<0.06
	50	--	--	--	--	--	--	37.5	<0.05	<0.05
	0-0-0-25 cycle	--	--	--	--	--	--	20.9 (25)	<0.04	--
Fluorene	25	--	--	--	--	--	--	1.2	--	0.1
	50	--	--	--	--	--	--	--	12.0	--
	0-0-0-25 cycle	--	--	--	--	--	--	17 (25)	6.0	<0.003

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-76)

TABLE 30.(continued)

Name of Compound	Dosage level mg/1	Concentration of Compound								
		Activated sludge (θ_c=5 days)			Extended aeration			Batch		
		Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent
Hexachloroethane	25	--	--	--	--	--	--	--	<0.02	<0.06
	50	--	--	--	--	--	--	--	0.08	--
	0-0-0-25 cycle	--	--	--	--	--	--	--	--	<0.05
Methylene chloride	5	1.8	<0.001	0.4	--	--	--	3 8	--	--
	25	--	<0.001	<0.026	--	--	--	29.9	<0.001	<0.001
	50	--	<0.036	<0.055	--	--	--	41.0	<0.07	<0.05
	0-25 cycle	--	--	--	8.5	--	--	--	--	<0.01
	0-0-25 cycle	--	--	<0.008	--	--	<0.001	--	<0.001	<0.001
Chlorobenzene	5	--	--	--	--	--	--	4.1	--	--
	25	--	--	--	--	--	--	33.6	<0.04	<0.8
	50	--	--	--	--	--	--	21.4	<0.6	<0.6
	0-0-25 cycle	--	--	--	--	--	--	23.6 (25)	<0.8	<0.8
Tetrachloro ethylene	25	--	--	--	--	--	--	14.4	<0.03	<0.03
	50	--	--	--	--	--	--	8.6	<0.44	<0.6
4-chloro, 3 methyl phenol	5	--	--	--	6.1	--	<1.6	7.1	<1.6	<1.6
	25	25.5	<0.08	<0.08	--	--	<1.05	21.4	--	3.8
	50	53.3	<0.08	1.1	--	--	<0.08	--	--	<1.3

(continued)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 30.(continued)

Name of Compound	Dosage level mg/1	Concentration of Compound								
		Activated sludge (θ_c=5 days)			Extended aeration			Batch		
		Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent
Ethylbenzene	5	--	--	--	--	--	--	--	<0.03	<0.03
	25	--	--	--	--	--	--	--	<0.03	<0.03
	50	--	--	--	--	--	--	59	<0.03	<0.03
Carbon Tetrachloride	5	--	--	--	--	--	--	1.4	--	--
	25	--	--	--	--	--	--	7.0	<0.1	<0.06
	50	--	--	--	--	--	--	21.7	<0.67	<0.5
	0-25	--	--	--	--	--	--	--	--	<0.8
	0-0-25 cycle	--	--	--	--	--	--	23.4 (25)	<0.6	<0.7
Chloroform	5	--	--	--	--	--	--	--	<0.2	<0.2
	25	--	--	--	--	--	--	14.2	<0.2	<0.2
	50	--	--	--	--	--	--	--	--	2.1
	0-25 cycle	--	--	--	--	--	--	--	--	<0.2
	0-0-25 cycle	--	--	--	--	--	--	27.5 (25)	<0.2	<0.2
Trichloroethylene	5	--	<0.01	--	--	--	--	3.1	<0.01	<0.01
	25	--	--	--	--	--	--	12.2	<0.01	<0.01
	50	50	<0.005	<0.005	--	--	--	50	<0.005	<0.008
	0-25 cycle	--	--	--	--	--	--	--	--	<0.01

(continued)

TABLE 30. (continued)

Name of Compound	Dosage level mg/1	Concentration of Compound								
		Activated sludge (θ_c=5 days)			Extended aeration			Batch		
		Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent	Feed	Mixed Liquor	Settled Effluent
	0-0-25 cycle	--	--	--	--	--	--	--	--	<0.01
1,2-Dichloroethane	5	--	--	--	--	--	--	--	<0.05	--
	25	9.6	<0.1	<0.1	--	--	--	--	<0.1	--
	50	22.8	<0.1	<0.08	--	--	--	--	<0.1	--
1,1,2-Trichloroethane	5	--	--	--	--	--	--	--	<0.02	<0.02
	50	--	--	--	--	--	--	--	<0.02	<0.02
Bromoform	5	--	--	--	--	--	--	--	<2.0	<2.0
	25	--	--	--	--	--	--	26.3	<0.02	<0.02
	50	--	--	--	--	--	--	38.6	<2.0	<2.0
Tetrachloroethane	5	--	--	--	--	--	--	0.8	--	<0.1
	25	--	--	--	--	--	--	32.4	<0.1	<0.1
	50	--	--	--	--	--	--	76	--	<0.1

present only at very low concentrations. The only studies that showed high effluent concentrations were batch nitrobenzene studies at a dosage level of 5 mg/l and continuous flow activated sludge ($\theta_c = 5$ days) 2-chlorophenol under a 25-50 cycle dosage. The nitrobenzene unit had a settled effluent concentration of 2.4 mg/l and 2-chlorophenol had an effluent concentration of 31.0 mg/l. The nitrobenzene data leaves questions because the mixed liquor under the same operating conditions showed a nitrobenzene concentration of <0.001 mg/l. No analysis was conducted on the mixed liquor of the 2-chlorophenol unit. Therefore, the same comparison cannot be made.

Anthracene and fluorene show high concentrations present in the mixed liquor with low concentrations present in the settled effluent. This indicates that the compounds were present as part of the biological solids, possibly attached to the surface.

These studies did not show the mechanisms for removing the test compounds. The compounds could have been removed by biological degradation, stripping, or by attachment to the surfaces of the microorganisms. However, the studies have shown that, in general, very low concentrations of the test compounds were present in the effluents. A very high percentage of each test compound was removed by some mechanism.

EPA-287 (Cin.)
(4-76)